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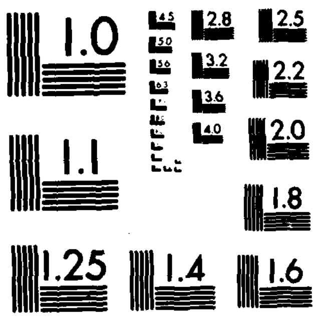

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

Computer Programs for Helicopter
High Speed Flight Analysis

by

Waldo Francisco Carmona

September 1983

Thesis Advisor: Donald M. Layton

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Computer Programs for Helicopter High Speed Flight Analysis

by

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Captain, United States Army
B.A., University of Dayton, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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September 1983

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ABSTRACT

This report gives the user of the HP41-CV handheld programmable calculator or the IBM 3033 computer, a blade element method for calculating the total power required in forward, straight and level high speed flight for an isolated rotor. The computer programs consist of a main program which calculates the necessary dynamic parameters of the main rotor and several subroutines which calculate power required as well as maximum forward velocity, stall onset velocity, and velocity for best endurance.

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I. INTRODUCTION

A. GENERAL

The basis for helicopter rotor analysis was developed in the early 1920's when Glauert extended propeller theory to the special case of rotating wings. Since that time, the development of the digital computer has permitted many improvements on Glauert's analysis.

In order to develop a method for predicting the total rotor power required in forward flight, it is necessary to develop a method that accurately predicts rotor dynamics. The prediction of rotor dynamics in forward flight is a complex one. Typically, a helicopter rotor blade encounters a flow environment which changes rapidly as it moves around in azimuth.

In forward flight, rotor blade sections are subjected to azimuthal variations in not only angle of attack but also Mach number. As a result, comprehensive performance analysis of a helicopter is much more involved than that of a conventional aircraft.

Recent helicopter design trends have been in the direction of increasing the maximum forward velocity possible as well as higher blade tip speeds. Since the

speed of the helicopter is added to the speed of rotation of the advancing blade, the highest relative velocities occur at the tip of the advancing blade. When the section Mach number of the blade tip exceeds the critical Mach number of the airfoil, compressibility effects result. These effects include a large increase in profile drag and change in pitching moments, therefore creating additional power requirements.

In all current helicopters there is a tendency for the retreating blade to stall. Just as the stall of an airplane wing limits the low speed perfomance of an airplane, the stall of a rotor limits the high speed potential of a helicopter. The relative velocity of the retreating blade decreases as forward speed increases. However, the retreating blades must produce the same amount of lift as the advancing blade. Therefore, as the relative velocity of the the retreating blade decreases with forward speed, the blade angle of attack must be increased to equalize lift throughout the the rotor disc area. As this angle increases the blade will eventually stall at some forward speed. For these reasons, stall and compressibility thus combine to limit the performance fo a helicopter at higher speeds.

For efficient design of a helicopter, the helicopter designer should have the analytical tools necessary to predict the performance of a helicopter. This report gives the user of the HP41-CV and the IBM 3033 computer a means of calculating the total power required in forward, straight and level flight.

B. OBJECTIVE

The objective was to provide an interactive computer program which can be used during the initial design stage to estimate the total power required by the main rotor of a helicopter, as well as maximum forward velocity possible, stall onset velocity, and best endurance velocity.

Additionally, the desired accuracy chosen at the beginning of this effort was to obtain angle of attack within a plus or minus one half degree, power estimates within ten per cent of the actual power required, and to obtain the needed accuracy in as short a running time as possible.

II. PROBLEM DEFINITION

A. DESCRIPTION OF PROBLEM

For a helicopter in level flight, the maximum forward speed is limited by the power available as well as stall and compressibility effects. It is therefore advantageous to develop a simple-to-use computer program that estimates blade stall and compressibility effects on helicopter performance.

B. METHOD OF SOLUTION

In forward flight, the aerodynamic environment of the rotor blade varies as the rotor blade rotates with respect to the direction of flight. The method chosen to obtain the objective accuracy ignores any variable not immediately impacting on the accuracy of the determination of angle of attack and power requirements.

The method utilized herein uses a combination of momentum and blade element theory to perform rotor performance calculations. This theory is initially used to determine the induced, profile, and parasite power required. The solution method then utilizes a blade element analysis to predict the cyclic, collective, and inflow angles

associated with the rotor. These angles are then used in the calculation of the rotor blade's angle of attack at the azimuthal positions of 90 and 270 degrees. Compressibility and stall power are then estimated as a function of angle of attack and forward velocity.

III. DESCRIPTION OF THE PROBLEM SOLUTION

A. GENERAL

The calculation/prediction of helicopter performance is primarily a matter of determining the power required and power available over the desired flight regime. The power information may then be used to predict the operational capabilities of the aircraft.

For the ideal helicopter (no losses), in forward, straight and level flight, power required can be subdivided into five parts: induced power, P_I, required to produce rotor thrust; profile power, P_O, required to overcome the skin friction and pressure drag of the main rotor; parasite power, P_P, required to overcome the parasite drag of the helicopter; compressibility power, P_M, required to overcome the increase in profile drag when the tip Mach number exceeds the drag divergence Mach number of the airfoil; and stall power, P_S, required to account for the increase in rotor torque as a result of retreating blade stall. The HP41-CV and IBM 3033 computer programs contained herein provides a simple, quick means of evaluating the power required by an isolated rotor.

B. ASSUMPTIONS

The major task in helicopter performance analysis is the determination of rotor forces, angles, and power. The method chosen ignores any variable that does not directly impact on the desired accuracy. Therefore, in order to simplify the computational process used, the following assumptions are made:

1. Steady flow through the rotor system.

2. Small angle approximations are a valid representation of the real world phenomena.

3. All blades considered are rectangular (non-tapered) with only uniform twist possible.

4. Hinge off-set is zero (i.e., the thrust vector passes through the C.G.).

5. The stall angle on most helicopter blades can be approximated by the angle that occurs at CLMAX for a 2-D airfoil.

6. The helicopter is trimmed. This implies that the sum of all the moments about the center of gravity (C.G.) is zero, all forces are in balance, and that no lateral flapping is present.

7. At stall onset, the value of section drag coefficient jumps approximately 0.08.

8. The rotor rotates counterclockwise.

C. NOMENCLATURE

"Standard" nomenclature is used. Appendix A contains an alphabetical list defining all the symbols and mnemonics used in the development of this report. Appendix B contains an alphabetical list of all HP41-CV displays used in the HP41-CV program.

D. INITIALIZATION

It is assumed that the initial design of the helicopter has been completed and that the helicopters weight as well as the chord, radius, tip velocity, twist, zero-lift drag coefficient, and number of blades of the rotor are known. Finally, it is assumed that an initial estimation of equivalent flat plate area is available, and that the forward velocity of the helicopter is known.

E. ROTOR DYNAMICS

There are four rotor parameters which will help expedite later calculations. The first of these is the rotor advance ratio, μ ; μ is the ratio of the helicopter's forward

velocity to the rotational velocity. The advance ratio can be represented as

$$\mu = \frac{V_F \cos\alpha}{V_T} \quad \text{(dimensionless)} \tag{1}$$

Applying small angle approximations the advance ratio becomes

$$\mu = \frac{V_F}{V_T} \tag{2}$$

where,

$$V_T = (\Omega R)$$

The second dimensionless ratio that needs to be calculated is the inflow ratio, λ. The inflow ratio is the ratio of the net velocity up through the rotor system to the tip speed. For the near hover case, $\mu < 0.1$, the $\tan\alpha = 0$ and the inflow ratio can be approximated by

$$\lambda = -\sqrt{CT/2} \tag{3}$$

In forward flight, the calculation of λ requires the determination of the angle of attack of the rotor disc. Letting the angle of attack between the disc plane and the

incoming free-stream velocity be α_3, and assuming angles to be small, the inflow velocity can be calculated using

(3a) $$\lambda = \frac{-C_T}{2\sqrt{\lambda^2+\mu^2}} + \mu \operatorname{Tan} \alpha_3$$

where

$$\alpha_3 = -\operatorname{Tan} (D_P/L) = -\operatorname{Tan} (D_P/W)$$

$$D_P = (P_P * 550) / V_F$$

The last dimensionless parameter that needs to be calculated is solidity. Solidity is the fraction of the rotor disc area that is composed of blades. For a blade of constant chord (i.e., non-tapered) solidity can be expressed as

(4) $$\sigma = (b * C)/(PI * R)$$

Finally, the tip loss factor, B_{TL}, must be considered. The tip loss factor is used to account for the loss of lift that a rotor blade experiances due to flow from the rotor's lower surface to its upper surface. The tip loss factor of a rotor can be approximated by

(5) $$B_{TL} = 1.0 - \sqrt{2 * CT} / b$$

F. VELOCITY CALCULATIONS

There are four velocities that are of interest. The first of these is the downwash velocity, w. Assuming steady flow through the rotor, the downwash velocity can be approximated by

$$(6) \qquad w = \frac{W}{2\rho A_D V_F} \qquad (ft/s)$$

NOTE: This equation is not valid for small values of forward velocity.

The second velocity that needs to be calculated is the stall onset velocity, V_S. The stall onset velocity is the velocity at which the retreating blade tip first exceeds the static stall angle. The forward speed at which stall onset is first noted can be approximated by the velocity for best range, VBR. This is due to the marked increase in profile power required at speeds higher than velocity for best range. A typical set of power curves for a helicopter are shown in Figure 3.1.

The forward velocity for minimum P/V (i.e., best range velocity) is easily found graphically on the power required curve as the point where a straight line through the origin

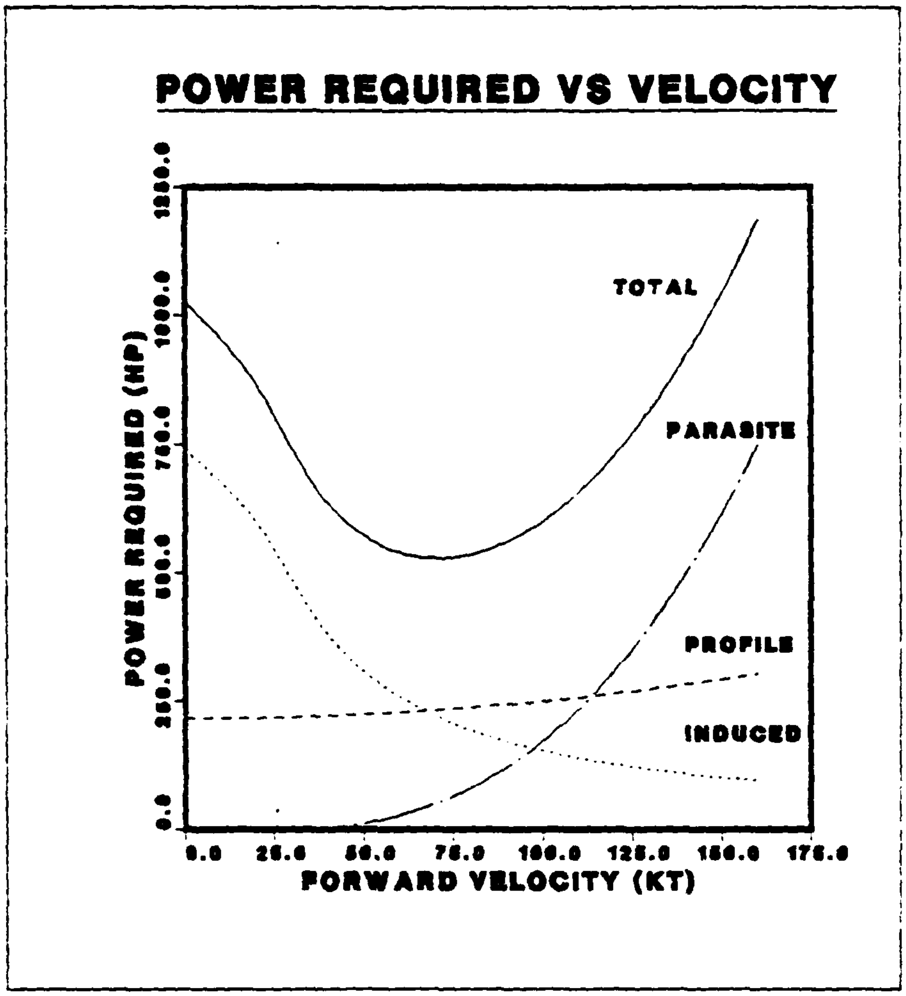


Figure 3.1. Typical Helicopter Power Curves

is tangent to the curve (see Figure 3.2). Since the power curves are not initally known, an analytical expression needs to be developed which will estimate the velocity for best range. The following is the derivation of one such expression.

As shown below, if the parasite power required is set equal to the profile power required and the equality is then solved for an equation in which forward velocity is the variable, the result is a cubic equation in which the largest root defines the point where the profile power and parasite power are equal.

$$P_P = P_O$$

$$1/2\, \rho f V_F^3 = 1/8\, \sigma\, Cdo\, \rho\, A_D (1 + 4.25\ \mu^2)$$

$$(7) \quad V_F^3 - (4.25\ /4f)\, Cdo\ A_D V_T\ V_F^2 - (\sigma/4f)\, Cdo\ A_D V_T^3 = 0$$

Next, the largest root of equation 7 needs to be determined. This can be simply done using the cubic root equation. Letting

$$p = -(4.25\, \sigma/4f)\, Cdo\ A_D V_T$$

$$r = -(\sigma/4f)\, Cdo\ A_D V_T{}^3$$

Equation 7 can now be written as

$$(7a) \quad V_F^3 - pV_F^2 - r = 0$$

Substituting

$$(X - p/3)$$

for V_F in equation 7a yields an equation of the form

$$X^3 + aX + b = 0 \tag{7b}$$

where,

$$a = -1/3\, p^2$$

$$b = 1/27\, (2p^2 + 27r)$$

The largest root of equation 7b is then given by

$$V = A + B \tag{8}$$

where,

$$A = \left[\frac{-b}{2} + \sqrt{\frac{b^2}{4} + \frac{a^3}{27}} \right]^{1/3}$$

$$B = \left[\frac{-b}{2} - \sqrt{\frac{b^2}{4} + \frac{a^3}{27}} \right]^{1/3}$$

Equation 8 can now be used as the initial approximation for stall onset velocity.

The third velocity which is of interest is the helicopter's maximum forward velocity, VMAX. As shown in

Figure 3.2, the maximum forward velocity is given by the intersection of the power required and power available curves for a given gross weight and altitude [Ref. 1].

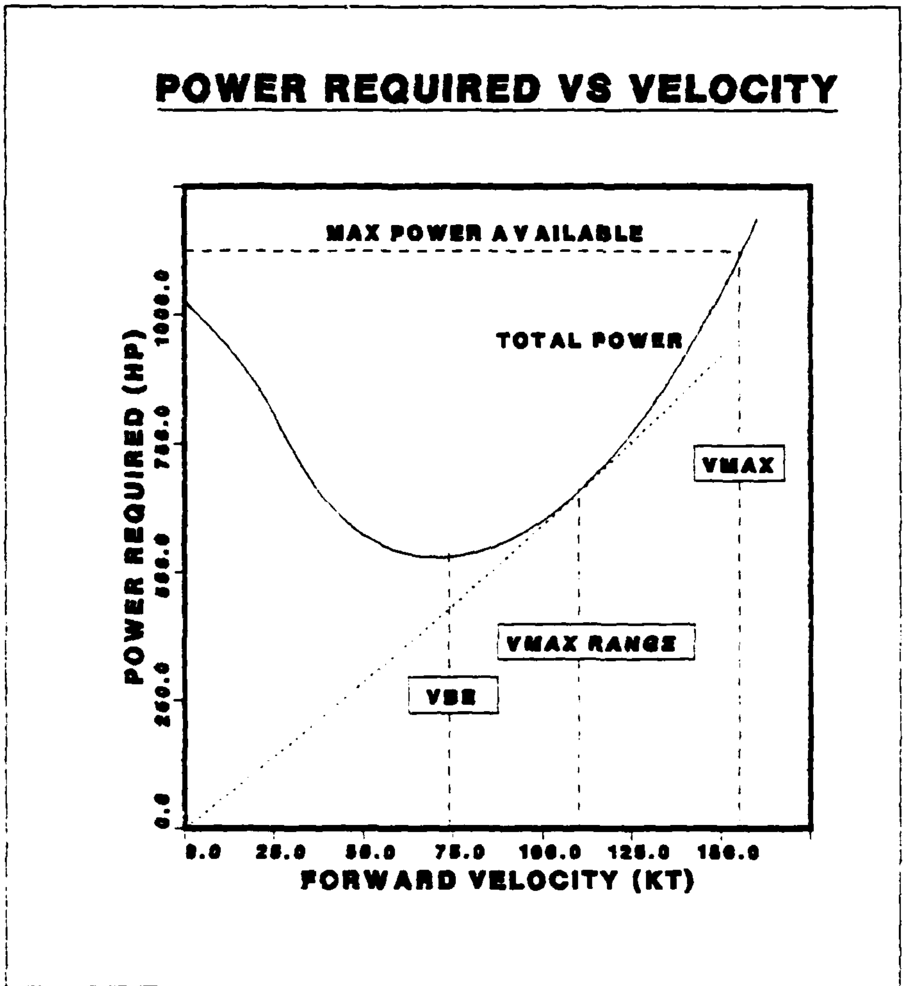


Figure 3.2. VMAX,VBE, and VS from Power Available Curves.

Therfore, whenever VF > VMAX, there is insufficient power available to sustain level flight.

The power-limited maximum speed may be estimated by

(9) $$V_{MAX} = \left[\frac{2}{\sigma f} (P_{AVAIL} - P_I - P_0) \right]^{1/3} \quad (ft/sec)$$

Equation 9 can be simplified by assuming that the power required at maximum speed is about the same as that required at hover. Therefore, assuming

(10) $$(P_{AVAIL} - P_I - P_0) = (P_{HOVER} - P_0)$$

and that

$$(P_{AVAIL} - P_0) = (P_I)_{HOVER} = \sqrt{\frac{W}{2\rho A_D}}$$

equation 9 can then be written as

(10a) $$V_{MAX} = v_I * (4/f/A_D)^{1/3} \quad (ft/s)$$

where,

(10b) $$v_I = \sqrt{\frac{W}{2 \rho A_D}}$$

The last velocity that needs to be calculated is the best endurance velocity, VBE. In the normal operating range the total helicopter power can be represented by

(11) $$P_T = P_I + P_0 + P_P$$

Assuming that the variation of profile power with forward velocity is negligible, the velocity for best endurance (also the best rate of climb velocity) can be found. If equation is differentiated with respect to forward velocity, VF, and is set equal to zero, it can be seen that

(11a) $$P_I = 3\ P_P$$

or

(11b) $$\frac{W^2}{2\ \rho\ A_D V_{BE}} = \frac{3\ \rho\ f\ V_F^2}{2}$$

Solving equation for the best endurance velocity, VBE, results in

(11c) $$VBE = \left[\frac{W}{\rho\ A_D} \left[\frac{A_D}{3f} \right]^{\frac{1}{2}} \right]^{\frac{1}{2}} \qquad \text{(ft/s)}$$

G. INITIAL POWER CALCULATIONS

As forward velocity increases, the induced power decreases, the profile power increases slightly, and the parasite power increases until it becomes the dominant loss at high speeds [Ref. 2]. For forward, straight and level flight, the induced power can be calculated by

$$P = W\left[-\frac{V_F^2}{2V_I^2} + \sqrt{\left(\frac{V_F^2}{2V_I^2}\right)^2 + 1}\right]^{\frac{1}{2}} V_I / 550 \quad \text{(hp)} \tag{12}$$

If tip losses are taken into effect (equation 5), the induced power now becomes

$$P_{I\,(TL)} = (1/B_{TL}) * P_I \tag{12a}$$

Since the induced power required in ground effect is less than that required out of ground effect, equation 12 should be written as

$$P_{I\,(TL+GE)} = (1/B_{TL}) * (GE) * P_I \tag{12b}$$

where,

$$GE = (-0.1276 * (h/D)^4 + 0.708 * (h/D)^3 - 1.4569 * (h/D)^2 + 1.3432 * (h/D) + 0.5147)$$

The profile power required is given by

$$P_O = \frac{\sigma C d o \rho A_D V_T^3 (1 + 4.25 \mu^2)}{4400} \quad \text{(hp)} \tag{13}$$

Finally, parasite power given by

$$(14) \qquad P_p = \frac{\rho f\, V_F^3}{1100} \qquad \text{(hp)}$$

H. ANGLE OF ATTACK

The determination of angle of attack at the azimuthal positions of 90 and 270 degrees are important in the determination of compressibility and stall effects. It is because of this effect that the dynamics of the blade motion are important in analyzing helicopter performance.

The angle of attack of the rotor is a function of radius, r, and azimuthal position, ψ . Figure 3.3 illustrates the sign convention used in determining blade angle of attack. The angle of attack of a rotor can thus be estimated by,

$$(15) \qquad \alpha(r, \psi) = \frac{\Theta - V_F \beta \cos \alpha + w - V \alpha_3}{\Omega R + V_F \sin \psi} \qquad \text{(rads)}$$

where,

$$(15a) \qquad \Theta = \Theta_O + \Theta_T + \Theta_1 \cos \Psi + \Theta_2 \sin \Psi + K_B \beta$$

$$(15b) \qquad \beta = \beta_O - a1 \cos \psi - b1 \sin \psi$$

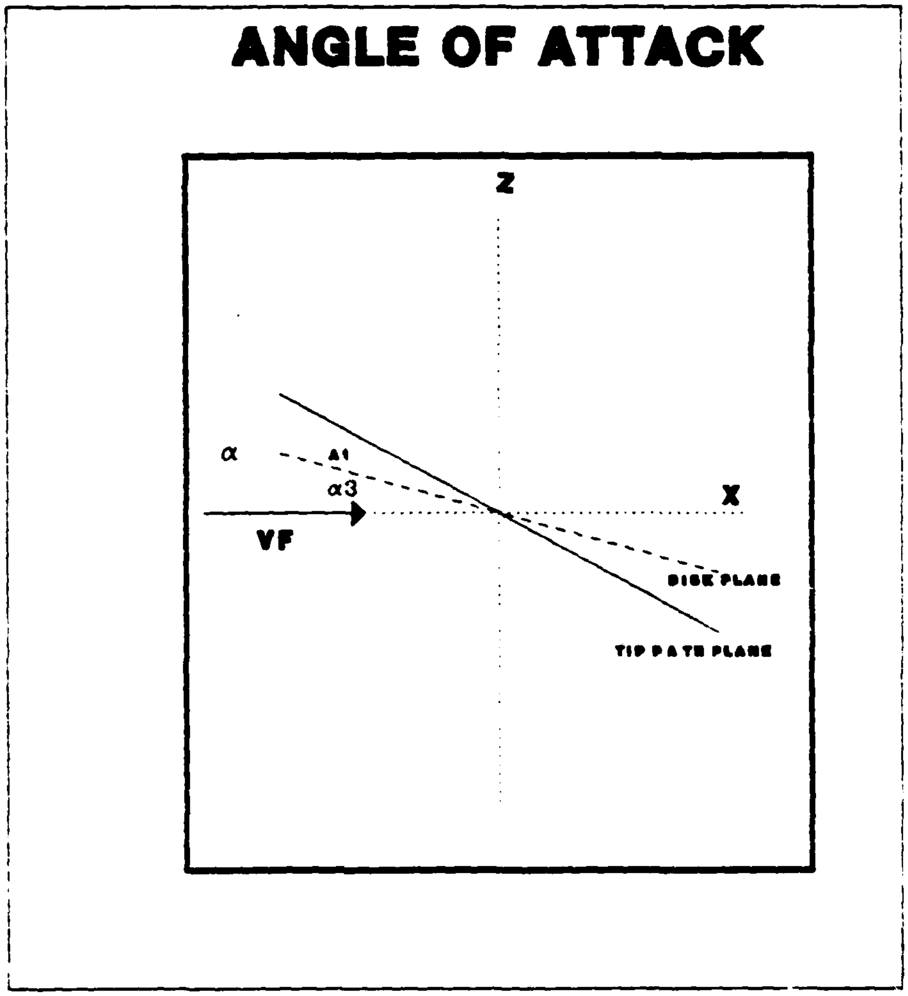


Figure 3.3. Rotor Angles in Longitudinal Plane.

To determine angle of attack, it is then necessary to determine the longitudinal collective and cyclic angles Θ_0 and Θ_2 . This can be accomplished by expressing the coefficient of thrust as

$$(16) \quad C_T = \frac{a\sigma}{2}\left[\lambda T1 + (\Theta_0 + K_B\beta)T2 + \Theta_T T3 + (\Theta_2 - K_B b1)T4\right]$$

where,

$$T1 = .5(B^2_{TL} + .5\mu^2) \qquad T3 = .25B^2_{TL}(B^2_{TL} + \mu^2)$$

$$T2 = (.5B^3_{TL} + .5\mu^2 B_{TL}) \qquad T4 = .5\mu(B^2_{TL} + .25\mu^2)$$

Additionally, the longitudinal flapping coefficient a1, needs to be determined. The longitudinal flapping coefficient can be written as

$$(17) \quad a1 = \lambda A11 + (\Theta_0 + K_B\beta_0)A12 + \Theta_T A13 + (\Theta_2 - K_B b1)A14$$

where,

$$D1 = (B^2_{TL} - .5\mu^2)$$

$$A11 = \frac{.25(.5B^2_{TL} - \mu^3/8)}{B^2_{TL}\,D1} \qquad A13 = \frac{2\mu B^2_{TL}}{D1}$$

$$A12 = \frac{8\mu B_{TL}}{3\,D1} \qquad A14 = \frac{B^2_{TL} + 1.5\mu^2}{D1}$$

Assuming that there is no lateral flapping and that the effect is zero (i.e., $K_B = 0.0$), equations 16 and 17 become

(18) $\quad \frac{2}{a} C_T = \lambda T1 + \Theta_0 T2 + \Theta_T T3 + \Theta_2 T4$

(19) $\quad a1 = \lambda A11 + \Theta_0 A12 + \Theta_T A13 + \Theta_2 A14$

NOTE: Since the analysis is only looking at the azimuthal positions of 90 and 270 degrees, it can be seen from equation 15b that the contribution of the longitudinal flapping coefficient, a1, will always be zero at these positions.

Equations 18 and 19 now represent a set of simultaneous equations in which the only unknowns are the collective and cyclic angles and can thus be determined. Knowing the values of the cyclic and collective angles, the blade tip angle of attack at the 90 and 270 degree positions can be estimated by

(20) $\quad \alpha_{90} = \Theta_0 + \Theta_T + \Theta_2 + \frac{\lambda}{1+u}$

(21) $\quad \alpha_{270} = \Theta_0 - \Theta_2 + \Theta_T + \frac{\lambda}{1+u}$

NOTE: The angle of attack, α, is defined positively if the disk plane is nose up, see Figure 3.2.

I. STALL POWER

In the helicopter stall normally starts at the tip of the retreating blade, since the highest angles of attack are usually at the blade tip. As the forward speed increases, the stalled area of the rotor blade spreads inboard.

At the higher values of μ, the effects of stall on power required are great and therefore need to be estimated. Assuming a jump of 0.08 in the value of Cdo at stall onset, that the rotor area within which the blade stall exists is a segment of minimum dimensionless radius X_S and that the stall area is symmetric about ψ = 270 degrees, Castles and New found that the effects of tip stall on power required at the higher values of μ are large and can be approximated for high speed flight by

$$(22) \qquad C_{PS} = \frac{\sigma}{24\,\pi} (1 - \mu)^2 (1 - X_S) \sqrt{1 - X_S^2}$$

where X_S is the nondimensional radius outboard of which the retreating blade is stalled [Ref. 3]. The dimensionless radius, X_S , can be estimated by equating the section angle of attack, at ψ = 270 degrees, to AMAX [Ref. 4]. Setting equation 15 at ψ = 270 degrees equal to AMAX results in the quadratic listed below.

(23) $(X-\mu) = \Theta_0(X-\mu) + \Theta_T X^2 - \Theta_T X\mu - \Theta_2(X-\mu) + \lambda + X \geq 1$

Applying the quadratic formula to equation 23 yields the roots

(23a) $$X_S = \frac{-B_S + \sqrt{B_S^2 - 4\Theta_T C_S}}{2\Theta_T}$$

(23b) $$X_0 = \frac{-B_S - \sqrt{B_S^2 - 4\Theta_T C_S}}{2\Theta_T}$$

where,

(23c) $$\Gamma = \alpha_{MAX} - \Theta_0 + \Theta_2$$

(23b) $$C_S = \mu\Gamma + \lambda$$

(23e) $$B = -\mu\Theta_T - \Gamma$$

Equation 22 is satisfactory for most cases. It is possible however, for the blade section angle of attack to be higher inboard than at the tip creating a situation which is ussually refered to as inboard stalling [Ref. 5].

For the special case of inboard stalling, see Figure 3.4, the incremental stall power coefficient defined by equation 22 is too large and needs to be corrected.

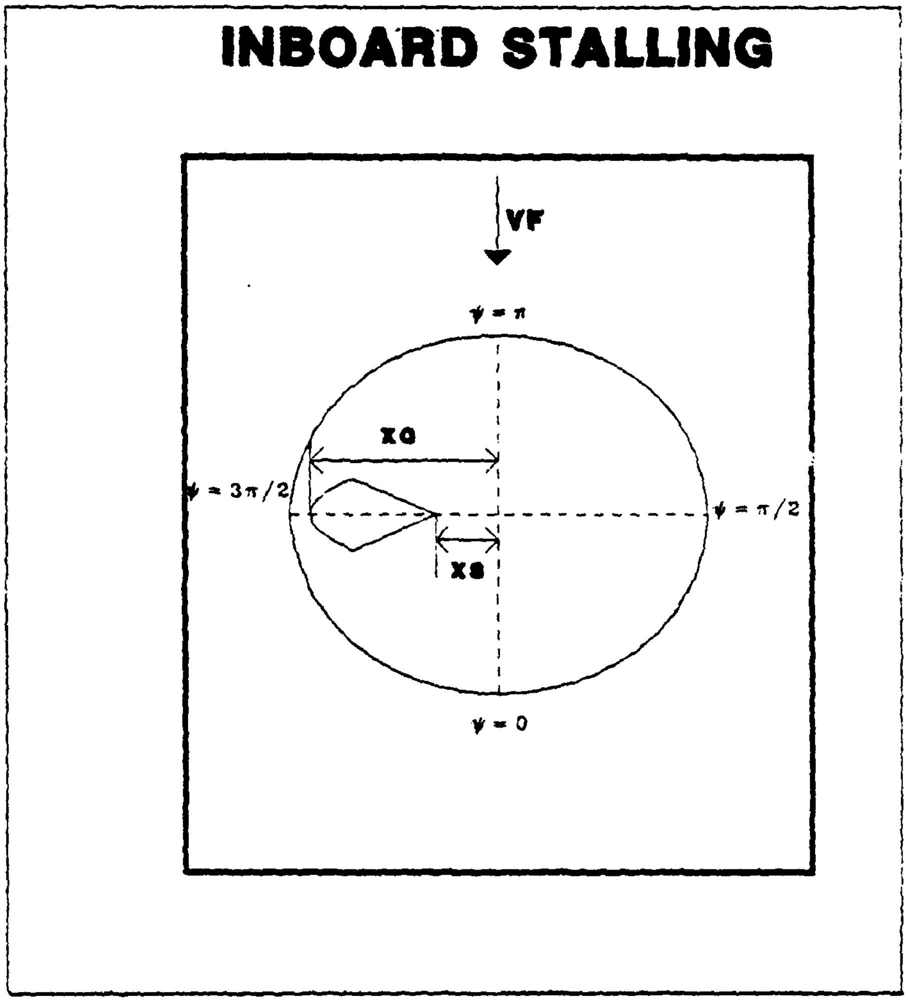


Figure 3.4. Inboard Stall Patern.

Assuming the stalled region is diamond shaped as shown in Figure 3.5 and that the stalled area is symmetric about $\psi = 3\pi/2$, it can be seen that as X_0 approaches X_S, the correction to the incremental stall power coefficient, C_{PS}, must vanish.

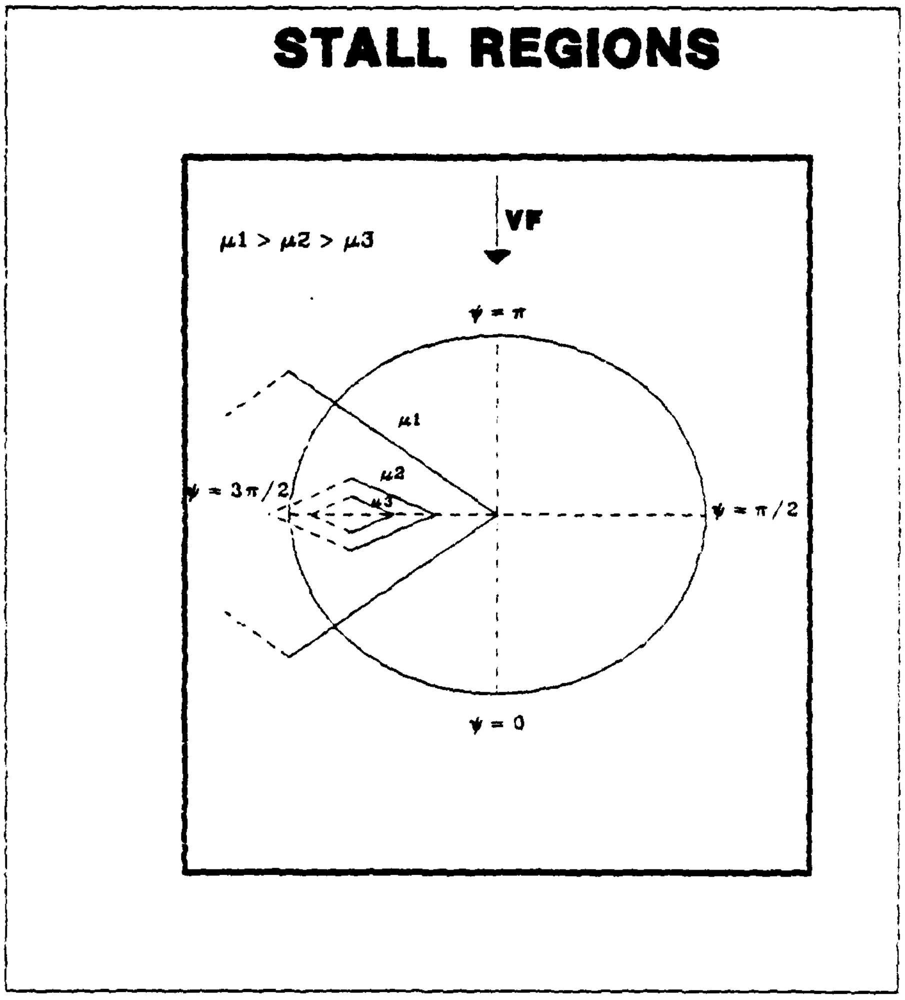


Figure 3.5. Approximated Stall Area.

Similiarly, as the average of X_0 and X_S approaches unity, the value of C_{PS} goes to the value defined by equation 22.

Therefore, in order to correct for the possibility of inboard stalling, the correction factor, k_S, is defined such that

(24) $\qquad k_S = 1.0 \qquad$ for $\quad \frac{-B_S}{2\Theta_T} > 1.0$

(25) $\qquad k = \frac{B_S/2\Theta_T + X_S}{1 - X_S} \qquad$ for $\quad \frac{-B_S}{2\Theta_2} < 1.0$

The corrected equation for stall power required thus becomes

(26) $\qquad C'_{PS} = k_S * C_{PS}$

J. COMPRESSIBILITY POWER

The individual effects of stall and compressibility on rotor profile power are substantial at high advance ratios. When both effects are present the losses due to each source are difficult to distinguish. Therefore, as a helicopter's forward velocity and tip speed increase, the need for a simple estimate of how the compressibility of the air influences the rotor performance is necessary.

In forward flight, the Mach number of the advancing blade is given by

(27) $M = M_{TIP}(x + \mu \sin\psi)$

where,

(27a) $M_{TIP} = \dfrac{\Omega R}{a_{SV}} = \dfrac{V_T}{a_{SV}}$

(27b) $x = r/R$ = nondimensional radius

Since the highest Mach number occurs at the tip of the advancing blade at ψ = 90 degrees, equation 27 can be written as

(28) $M_{90} = M_{TIP}(1 + \mu)$

Reference 3.5 showed that the critical Mach number for drag divergence can be estimated by

(29) $M_{CRIT} = MCR0 - m1 * a * x_{90}$

Gesssow and Crim, in their investigation of compressibility found that the compressibility effect on rotor performance was a rapid increase in the profile power when the tip Mach number exceeded the critical Mach number for drag divergence [Ref. 6]. The increase in profile power coefficient due to Mach effects can be estimated by

(30) $$C_{PC} = 0.01\,\Delta M_D + 0.1(\Delta M_D)^3$$

where,

(31) $$\Delta M_D = M_{90} - M_{CRIT} - 0.06$$

IV. CONCLUSIONS AND RECOMMENDATIONS

The objective of this project was to provide an easy to use, inter-active computer program which could be used during the initial design phase to estimate the total power required by the main rotor of a helicopter. The computer programs contained herein provide results which are well within the objective accuracies (see Figures C.1, C.2, C.3) and provide acceptable results as a first cut estimate of compressibility and stall power requirements.

In the development of the computational model, many simplifying assumptions were made to ease the amount of computation required. The assumption which most impacts on the accuracy of the program is that of steady flow through the rotor.

The flow environment encountered by the rotor changes rapidly due to the rate of change of blade angle of attack.. Additionally, rotor operation at high advance ratios also produces considerable radial flow along the blade span . The steady flow assumption ignores the time-variant aspect of rotor aerodynamics. The dynamic nature of the rotor, especially when operating at or near the stall regime, requires the application of unsteady aerodynamics, and a

close examination of how the pitching moments generated by the retreating blade stalling affects controlability [Ref. 7]. It is therefore recomended that additional investigations consider how the unsteady aerodynamics, and pitching moments generated, influence the performance of the helicopter.

APPENDIX A

NOMENCLATURE

Term	Mnemonic	Definition	Units
a	a	Slope of airfoil section lift curve.	rad
A	AD	Rotor disc area.	ft
α_3	Alpha3	Disk plane angle of attack.	rad
α_{MAX}	AMAX	The steady flow stall angle of the airfoil (given by a * CLMAX).	rad
α_{90}	A90	Angle of attack of the advancing blade at ψ = 90 degrees.	rad
α_{270}	A270	Angle of attack of the retreating blade at ψ = 270 degrees.	rad
a1	a1	Longitudinal flapping	rad
A11	A11	Term in definition of THETA2.	dimensionless
A12	A12	Term in definition of THETA2.	dimensionless

A13	A13	Term in definiton of THETA2.	dimensionless
A14	A14	Term in definition of THETA2.	dimensionless
b	b	Number of blades on the main rotor.	dimensionless
β_0	BETA0	Main rotor coning angle.	rad
B_S	BS	Term in definition of X_S.	dimensionless
B_{TL}	BTL	Tip loss factor.	dimensionless
c	C	Mean chord of main rotor blade.	ft
C_{do}	CD0	Main rotor coefficient of drag at zero lift.	dimensionless
CL_{MAX}	CLMAX	Maximum coeficient of lift (2-D).	dimensionless
C_{PC}	CPC	Correction to power coefficient due to compressibility effects.	dimensionless
C_{PS}	CPS	Correction to power coefficient due to stall.	dimensionless
C_S	CS	Term in definition of X_S.	dimensionless

C_T	CT	Coefficient of thrust of the main rotor.	dimensionless
D_P	D	Rotor disc diameter.	ft
D	DP	Parasite drag of the helicopter.	lb
ΔM_D	DMD	Term in the definition of compressibility power.	dimensionless
δ_3	DEL3	Rate of change of blade pitch with respect to blade flapping.	dimensionless
f	FPA	Equivalent flat plate area of the helicopter in forward flight.	ft
Γ	GAMMA	Term in definition of B and C .	dimensionless
G.E.	GE	Ground effect ratio.	dimensionless
h	H	Height of main rotor above the ground.	ft
hp	HP	Horsepower.	hp
K	KB	effect.	dimensionless

λ	LAMB	Ratio of the net velocity up through the rotor system to the tip speed.	dimensionless
M	MACH	Mach number of rotor blade.	dimensionless
M_{CRIT}	MCRIT	Critical Mach number of advancing blade at ψ = 90 degrees.	dimensionless
M_T	MT	Tip Mach number of rotor balde.	dimensionless
M_{CRTO}	MCRTO	Critical Mach number for Cl = 0.0 .	dimensionless
μ	MU	Main rotor advance ratio.	dimensionless
m1	M1	Constant in definition of critical Mach number (m1 = 0.113).	ft-lb
Ω	OMEGA	Rotational velocity.	rad/s
P_C	PM	Power required due to compressibility effects.	hp
P_I	PI	Induced power.	hp

P_O	PO	Profile power.	hp
P_P	PP	Parasite Power.	hp
P_S	PS	Power required due to stall effects.	hp
R	R	Main rotor radius.	ft
ρ	RHO	Air density.	slug/ft
σ	SD	Main rotor solidity.	dimensionless
Θ	THETA	Ratio of ambient temperature to standard sea level temperature.	dimensionless
Θ_0	THETA0	Main rotor collective pitch.	rad
		Main rotor lateral pitch.	rad
Θ_2	THETA2	Main rotor longitudinal cyclic pitch.	rad
T1	T1	Term in definition of THETA0.	dimensionless
T2	T2	Term in definition of THETA0.	dimensionless
T3	T3	Term in definition of THETA0.	dimensionless
T4	T4	Term in definition of	dimensionless

		THETA0.	
V_I	VI	Induced velocity.	ft/s
V_F	VF	Aircraft forward speed.	ft/s
V	VKT	Aircraft forward speed.	kt
VMAX	VMAX	Maximum forward velocity possible.	kt
V_S	VS	Stall onset velocity (velocity at which A270 equal AMAX)	kt
V_T	VT	Rotor tip speed.	ft/s
a_{SV}	SVEL	Speed of sound.	ft/s
w	DW	Rotor downwash velocity.	ft/s
W	W	Aircraft gross weight.	lb
X_S	XS	Radius outboard of which the main rotor is stalled.	dimensionless
X_0	XO	Radius inboard of which rotor blade stall may be present due to inflow ratio and blade twist.	dimensionless

APPENDIX B

HP 41-CV PROGRAM DOCUMENTATION

A. GENERAL

The HP 41-CV program uses 45 program storage registers. Prior to program initialization, the handheld calculator should be sized to 46.

The computer program consists of a main program which calculates the necessary dynamic parameters of the main rotor and several subroutines which calculate power required as well as the maximum forward velocity, stall onset velocity, and best endurance velocity.

The documentation for the HP 41-CV program is devided into the following sections:

1. PURPOSE

This section describes the intended purpose of the program or subroutine.

2. ASSUMPTIONS

This section lists any assumptions made which are applicable to the program or subroutine.

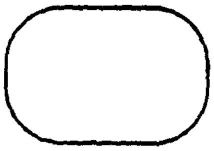
2. EQUATIONS

This section lists the equations utilized within the main program or subroutine. The primary references for

the equations used are *Aerodynamics and V/STOL Flight*, Reference 3.1, *Helicopter Theory*, Reference 3.2, and *Aircraft Performance*, Reference 3.3.

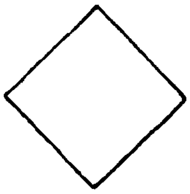
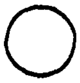
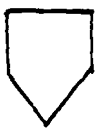
4. FLOWCHART

Both the handheld computer and the IBM 3033 normally execute instructions in a program in a sequential manner unless it is instructed to do otherwise. This section will graphically represent the step by step method used to solve the problem as well as the flow of control between the various parts of the program. In a flowchart, different types of operations are indicated by different shaped boxes as illustrated below:



Oval — For start or stop.

Rectangle — For a calculation or process other than a decision.

	Modified Rectangle	For the execution of a subroutine.
	Diamond	For a decision.
	Parallelogram	For input or output.
	Small Circle	For an on page connection when a flowchart continues on the same page, or when it is difficult to connect two boxes.
	Pentagon	For connection when a flowchart continues to another page.

5. PROGRAMS AND SUBROUTINES

This section lists all the programs or subroutines which must be present in the HP 41-CV prior to program execution.

6. PROGRAM LISTING

This section contains the HP 41-CV listing of the program or subroutine.

B. QUICK REFERENCE TABLES

The tables in this section will be useful to the user of the HP 41-CV handheld calculator as a source of quick reference. Table 1 is an alphabetical listing of all calculator displays with an explanation of their respective meaning. Table 2 lists all storage registers used and describes how they are utilized.

1. HP41-CV Displays

TABLE I

DISPLAY	DEFINITION	UNITS
a = ?	Slope of airfoil lift curve.	rad
b = ?	Number of main rotor blades.	N/A
c = ?	Chord length of main rotor.	ft
DA = ?	Density altitude.	ft
Cdo = ?	Main rotor coefficient of drag at zero lift.	N/A
FPA = ?	Equivalent horizontal flat plate area of the helicopter.	ft
h = ?	Height of the main rotor above the ground.	ft
MCR0=?	Critical Mach number for the coefficient of lift equal to zero.	N/A
R = ?	Main rotor radius.	ft
TWIST = ?	Geometric twist of the rotor.	rad
VF(KT) = ?	Forward velocity.	Kt
VT = ?	Rotor tip speed.	ft/s
W = ?	Aircraft gross weight.	lbs
COLL =	Main rotor collective pitch.	rad

CYCLIC =	Main rotor cyclic pitch.	rad
PI =	Induced power required compensated for tip losses and ground effect.	hp
PM =	Power required due to compressibility effects.	hp
PO =	Profile power required.	hp
PS =	Power required due to the retreating blade stalling.	hp
VBE =	Maximum endurance velocity.	Kt
VF > VMAX	The forward velocity that has been input is larger than the one calculated by subroutine VMAX.	N/A
VMAX =	Maximum forward velocity.	Kt
VS =	Initial estimate for finding onset velocity.	Kt
XS =	Radius outboard of which the main rotor is stalled.	N/A
XO =	Radius inboard of which rotor blade stall may be present.	N/A
α90D =	Angle of attack of the advancing blade at = 90 degrees.	deg
α270 =	Angle of attack of the retreating	deg

blade at ψ = 270 degrees.

2. H241-CV Register Utilization

TABLE II

STORAGE REGISTER	STORED QUANTITY/USE
00	Ground effect ratio (GE).
01	Maximum forward velocity (VMAX).
02	Stall onset velocity (VS).
05	Rotor radius (R).
06	Number of blades (b).
07	Zero-lift drag coefficient (Cdo).
09	Rotor height above the ground (h).
10	Aircraft gross weight (W).
11	Air density (RHO).
12	Lift curve slope (a).
13	Rotor tip velocity (VT).
14	Coefficient of thrust (CT).
15	Tip-loss factor (BTL).
16	Main rotor induced power (PI).
17	Rotor height to rotor diameter ratio (h/d).
18	Compressibility power (PC).

19	Solidity (SD).
20	Induced velocity (VI).
21	Main rotor profile power (PO).
22	Advance ratio (MU).
23	Stall power (PS).
24	Advance ratio squared (MU^2).
25	Forward velocity (VF).
26	Equivalent horizontal flat plate area (FPA).
27	Maximum 2-D lift coefficient (CLMAX).
28	Main rotor parasite power (PP).
29	Main rotor geometric twist (TWIST).
41	Angle of attack at 270 degrees (A270).
42	Angle of attack at 90 degrees (A90).
43	Sonic velocity (SVEL).
44	Critical Mach number for coefficient of lift equal to zero (MCR0).
45	Density altitude.
OTHERS	Scratch pad calculations.

C. PROGRAM DOCUMENTATION

This section contains the necessary documentation for the HP 41-CV computer program. The main program as well as all of the subroutines used in the solution of the problem are outlined in this section.

1. Main Program

(a) PURPOSE

This program calculates the dynamic parameters of the main rotor which are necessary for calculating the total main rotor power required in forward, high speed straight and level flight. It additionally controls the execution sequence of the various subroutines which are used to calculate main rotor power required, in terms of horsepower, as well as maximum forward velocity, stall onset velocity and velocity for best endurance in knots.

(b) ASSUMPTIONS

(1) All angles are small.

(2) Steady flow through the rotor.

(3) All rotor blades are rectangular (non-tapered) with only uniform twist being possible.

(4) Only the first hamonic of flapping is necessary for calculating power required.

(4) The effective dimensionless radius can be approximatedy by the tip-loss factor.

(6) The thrust vector passes through the C.G..

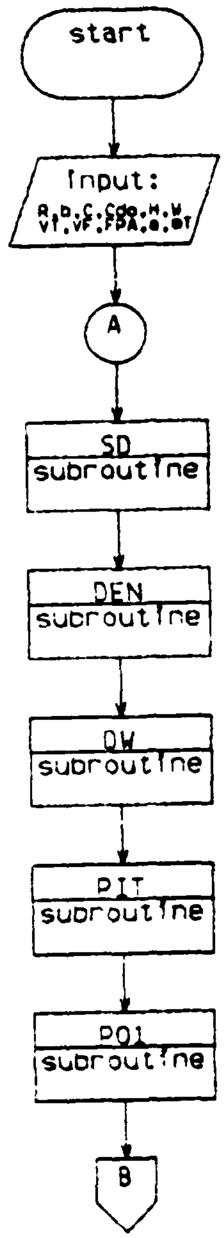
(7) The static stall angle for blades on most helicopters can be approximated by the angle at which CLMAX occurs for the 2-D airfoil.

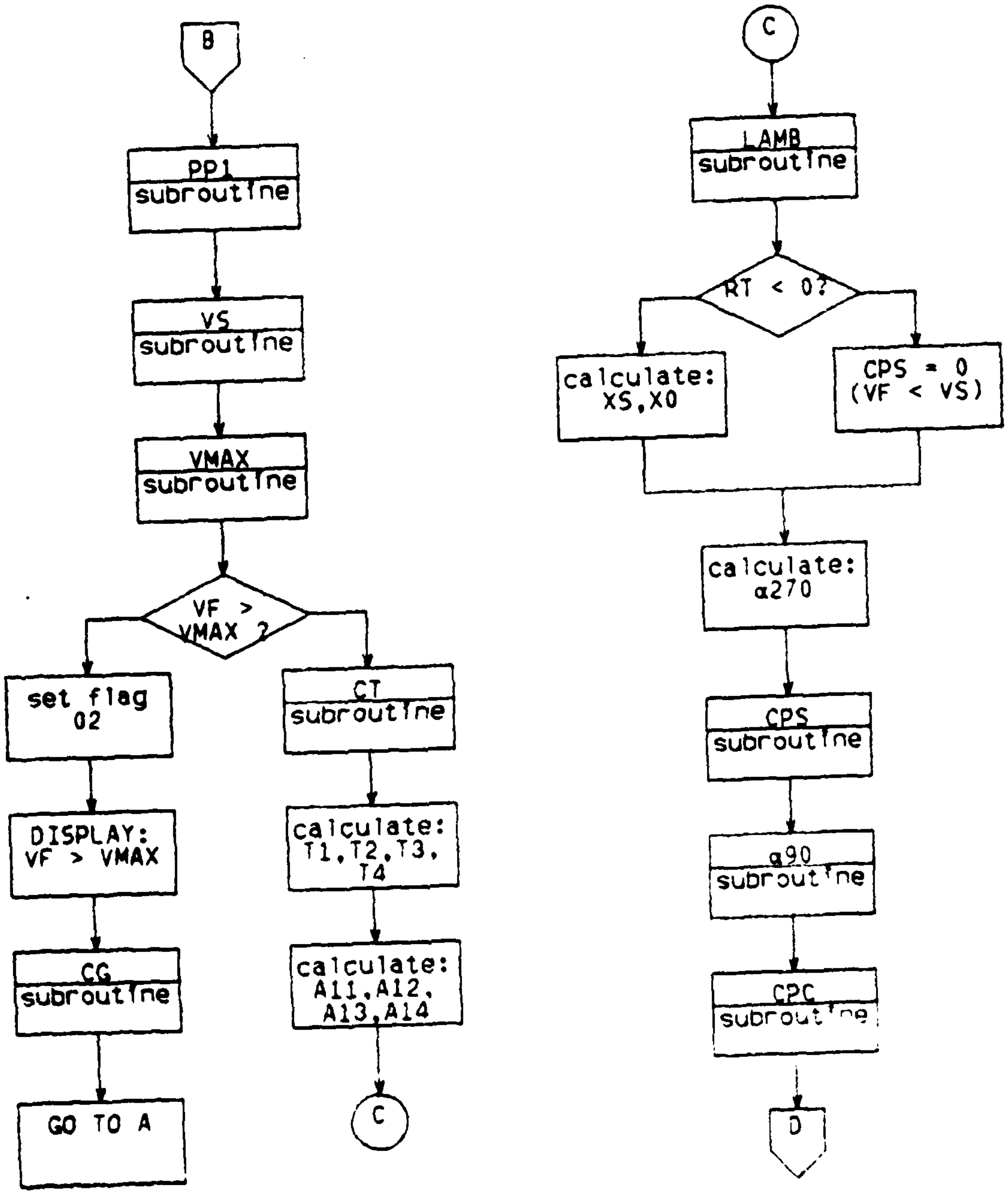
(8) The δ 3 effect, or the result of cocking the flapping axis of the blade so that its pitch varies as the blade flaps is zero (i.e., no lateral flapping is present).

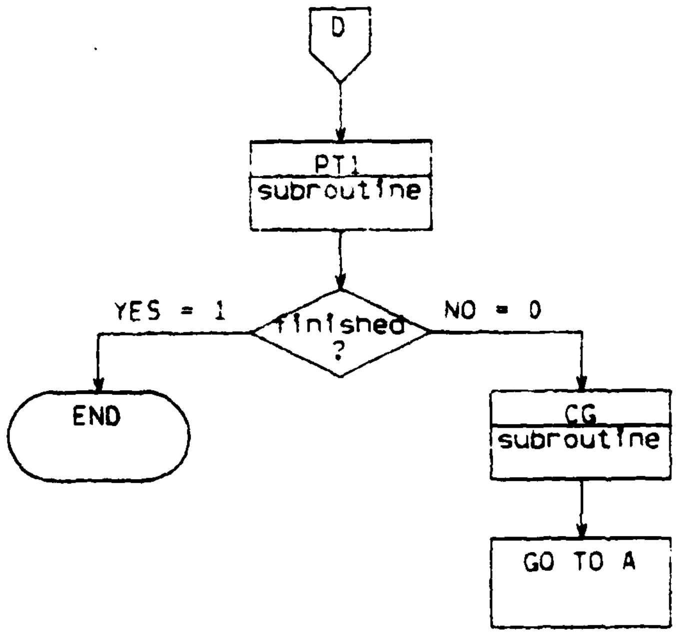
(c) EQUATIONS

$$\mu = V_F/V_T$$
$$V_F\ (ft/s) = V * 1.68894$$
$$T1 = .5(B_{TL}^2 + .5\ \mu^2)$$
$$T2 = .334B_{TL}^3 + .5\ \mu^2 B_{TL}$$
$$T3 = .25B_{TL}^2(B_{TL}^2 + \mu^2)$$
$$T4 = .5\mu(B_{TL}^2 + .25\ \mu^2)$$
$$D1 = (B_{TL}^2 - .5\ \mu^2)$$
$$A11 = 4(.5\ B_{TL}^2 - \mu^3\ /8)/D1$$
$$A12 = 8\mu B_{TL}/3D1$$
$$A13 = 2\mu B_{TL}^2\ /\ D1$$
$$A14 = (B_{TL}^2 + 1.5\ \mu^2)\ /\ D1$$
$$(2CT/\sigma a) = \lambda T1 + \theta_0 T2 + \theta_T T3 + \theta_2 T4$$
$$0 = \lambda A11 + \theta_0 A12 + \theta_T A13 + \theta_2 A14$$
$$Amax = CLMAX/CLA$$
$$a270 = \theta_0 - \theta_2 + \theta_T + (\lambda / 1 + \mu)$$
$$\Gamma = AMAX - \Theta_0 - \Theta_2$$
$$C_S = \mu\Gamma + \lambda$$
$$B_S = -\mu\theta_T - \Gamma$$
$$X_S = -B_S + (B_S^2 - 4\theta_T C_S)^{.5}\ /\ 2\theta_T$$
$$X_0 = -B_S - (B_S^2 - 4\theta_T C_S)^{.5}\ /\ 2\theta_T$$

d. FLOWCHART


start
Input:
A
SD
subroutine
DEN
subroutine
DW
subroutine
PIT
subroutine
PO1
subroutine
B


B
PP1 subroutine
VS subroutine
VMAX subroutine
VF > VMAX ?
set flag 02
DISPLAY: VF > VMAX
CG subroutine
GO TO A
CT subroutine
calculate: T1,T2,T3, T4
calculate: A11,A12, A13,A14
C
C
LAMB subroutine
RT < 0?
calculate: XS,X0
CPS = 0 (VF < VS)
calculate: α270
CPS subroutine
α90 subroutine
CPC subroutine
D



e. PROGRAMS AND SUBROUTINES USED

" SD "	" CT "
" PIT "	" LAMB "
" PO1 "	" CPS "
" PP1 "	" CPC "
" VS "	" α90 "
" VMAX "	" CNG "
" DEN "	

f. PROGRAM LISTING

```
01◆LBL "WBS"
02 "R=?"
03 PROMPT
04 STO 05
05 "b=?"
06 PROMPT
07 STO 06
08 "C=?"
09 PROMPT
10 STO 04
11 "CdO=?"
12 PROMPT
13 STO 07
14 "W=?"
15 PROMPT
16 STO 10
17 "VT=?"
18 PROMPT
19 STO 13
20 "VF(KT)=?"
21 PROMPT
22 1.68894
23 *
24 STO 25
25 "FPA=?"
26 PROMPT
27 STO 26
28 "H=?"
29 PROMPT
30 STO 09
31 "a=?"
32 PROMPT
33 STO 12
34 "CLMAX=?"
35 PROMPT
36 STO 27
37 "TWIST=?"
38 PROMPT
39 STO 29
40 "NCR0=?"
41 PROMPT
42 STO 44
43 "DA=?"
44 PROMPT
45 STO 45

46◆LBL "AGN"
47 RCL 25
48 RCL 13
49 /
50 STO 22
51 X↑2
52 STO 24
53 XEQ "SD"
54 XEQ "DEN"
55 FS? 03
56 GTO 05
57 XEQ "PIT"
58 XEQ "P01"

59◆LBL 05
60 XEQ "PP1"
61 ADV
62 FS? 03
63 GTO 06
64 XEQ "VBE"
65 XEQ "VMAX"
66 ADV

67◆LBL 06
68 XEQ "CT"
69 RCL 15
70 X↑2
71 STO 30
72 ENTER↑
73 RCL 24
74 2
75 /
76 +
77 STO 31
78 2
79 /
80 STO 33
81 RCL 15
82 3
83 Y↑X
84 3
85 /
86 ENTER↑
87 RCL 24
88 RCL 15
89 *
90 2
91 /
92 +
93 STO 34
94 RCL 30
95 RCL 24
96 +
97 RCL 30
98 *
99 4
100 /
101 STO 35
102 RCL 30
103 RCL 24
104 4
105 /
106 +
107 RCL 22
108 *
109 2
110 /
111 STO 36
112 RCL 22
113 RCL 30
114 *
115 2
116 /
117 RCL 22
118 3
119 Y↑X
120 8
121 /
122 -
123 4
```

```
124 *
125 RCL 30
126 ENTER↑
127 RCL 24
128 2
129 /
130 -
131 STO 32
132 RCL 30
133 *
134 /
135 STO 37
136 RCL 22
137 RCL 15
138 *
139 8
140 *
141 3
142 /
143 RCL 32
144 /
145 STO 38
146 RCL 22
147 2
148 *
149 RCL 30
150 *
151 RCL 32
152 /
153 STO 39
154 RCL 30
155 ENTER↑
156 RCL 24
157 1.5
158 *
159 +
160 RCL 32
161 /
162 STO 40
163 RCL 14
164 2
165 *
166 RCL 12
167 /
168 RCL 19
169 /
170 STO 42
171 XEQ "LAMB"
172 RCL 03
173 RCL 33
174 *
175 CHS
176 RCL 42
177 +
178 RCL 29
179 RCL 35
180 *
181 -
182 STO 31
183 RCL 03
184 CHS
185 RCL 37
186 *
187 RCL 29
188 RCL 39
189 *
190 -
191 STO 32
192 RCL 34
193 *
194 ENTER↑
195 RCL 31
196 RCL 38
197 *
198 -
199 RCL 34
200 ENTER↑
201 RCL 40
202 *
203 RCL 36
204 ENTER↑
205 RCL 38
206 *
207 -
208 /
209 STO 32
210 FS? 03
211 GTO 07
212 R-D
213 "CYCLIC="
214 ARCL X
215 AVIEW
216 STOP

217♦LBL 07
218 RCL 31
219 ENTER↑
220 RCL 36
221 RCL 32
222 *
223 -
224 RCL 34
225 /
226 STO 33
227 FS? 03
228 GTO 08
229 R-D
230 "COLL="
231 ARCL X
232 AVIEW
233 STOP
234 ADV

235♦LBL 08
236 RCL 33
237 RCL 32
238 -
239 RCL 29
240 +
241 ENTER↑
242 RCL 03
243 1
244 RCL 22
245 +
```

```
/
+
STO 41
FS? 03
GTO 09
R-D
"∠270="
ARCL X
AVIEW
STOP
ADV
XEQ "∠90"
ADV
RCL 27
RCL 12
/
RCL 33
-
RCL 32
+
STO 30
RCL 22
CHS
RCL 29
*
RCL 30
-
STO 31
RCL 30
RCL 22
*
RCL 03
+
STO 35
4
CHS
*
RCL 29
*
STO 35
RCL 31
X↑2
STO 36
ENTER↑
RCL 35
CHS
X>Y?
SF 01
FS? 01
GTO 03
RCL 36
RCL 35
+
SQRT
STO 38
RCL 31
CHS
+
RCL 29
/
2
/
STO 30
"XS="
ARCL X
AVIEW
STOP
RCL 31
CHS
RCL 38
-
RCL 29
/
2
/
STO 08
"XO="
ARCL X
AVIEW
STOP
ADV
♦LBL 03
XEQ "CPS"
ADV
CF 01
CF 02
CF 03
XEQ "CPC"
ADV
ADV
XEQ "PT!"
XEQ "CNG"
♦LBL 09
XEQ "VS"
END
```

2. Solidity

a. PURPOSE

This subroutine calculates the ratio of total blade area to the total rotor disc area.

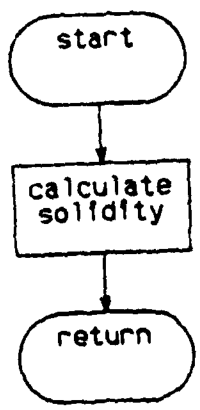
b. ASSUMPTIONS

None

c. EQUATIONS

$$\sigma = \frac{b * c * R}{PI * R^2} = \frac{b * c}{PI * R}$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01*LBL "SD"
02 RCL 06
03 RCL 04
04 *
05 RCL 05
06 /
07 PI
08 /
09 STO 19
10 END
```

3. Downwash Velocity

a. PURPOSE

The purpose of this subroutine is to compute the induced velocity of a rotor system.

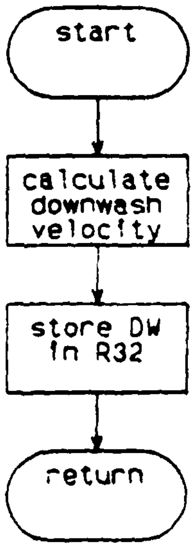
b. ASSUMPTIONS

Steady flow through the rotor system.

c. EQUATIONS

$$w = \frac{W}{2 \rho A_D V_F}$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

" WBS"

f. PROGRAM LISTING

```
01♦LBL "W"
02 RCL 25
03 X=0?
04 GTO 05
05 RCL 10
06 2
07 RCL 11
08 *
09 RCL 25
10 *
11 PI
12 *
13 RCL 05
14 X↑2
15 *
16 /
17 STO 64
18 GTO 06

19♦LBL 05
20 SF 03

21♦LBL 06
22 END
```

4. Coefficient of Thrust

a. PURPOSE

This subroutine calculates the coefficient of thrust for a arbitrary rotor.

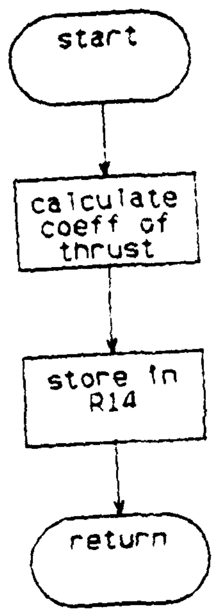
b. ASSUMPTIONS

Steady flow through the rotor system.

c. EQUATIONS

$$CT = \frac{W}{\rho A_D V_T^2}$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01*LBL "CT"
02 RCL 05
03 X↑2
04 PI
05 *
06 RCL 11
07 *
08 RCL 13
09 X↑2
10 *
11 1/X
12 RCL 10
13 *
14 STO 14
15 END
```

5. Induced Power

(a) PURPOSE

This subroutine calculates the power required by the rotor to produce thrust at hover and forward flight. Additionally, this subroutine corrects for tip losses (losses in lift at the tips due tip votices) as well as ground effect.

(b) ASSUMPTIONS

Steady flow through the rotor system.

(c) EQUATIONS

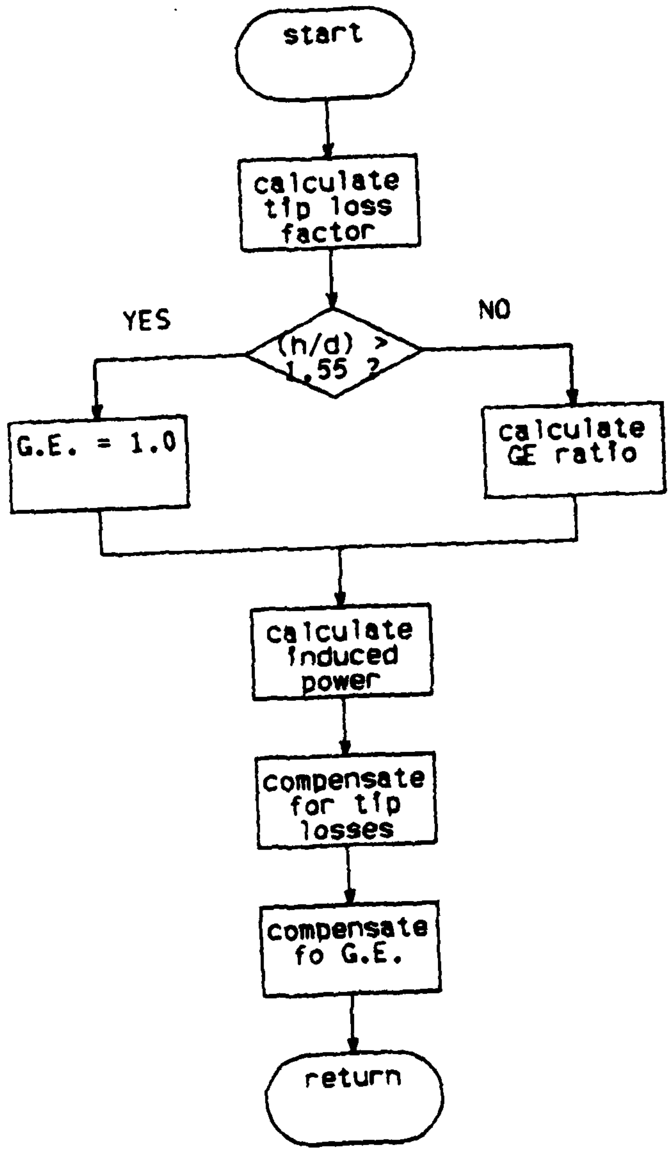
$$PI = W \left[-\frac{V_F^2}{2v_I^2} + \sqrt{\left(\frac{V_F^2}{2v_I^2}\right)^2 + 1} \right]^{1/2} v_I$$

$$B = 1.0 - \sqrt{\frac{2\ CT}{b}}$$

$$GE = -0.1276(h/D)^4 + 0708(h/D)^3 - 1.4569(h/D)^2 + 1.3432(h/D) + 0.5147$$

$$PIT = (1/B)*(GE)*PI$$

d. FLOWCHART


start
calculate tip loss factor
YES
NO
(h/d) > 1.55 ?
G.E. = 1.0
calculate GE ratio
calculate induced power
compensate for tip losses
compensate fo G.E.
return

e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01♦LBL "PIT"
02 RCL 14
03 2
04 *
05 SQRT
06 RCL 06
07 /
08 CHS
09 1
10 +
11 STO 15
12 RCL 09
13 RCL 05
14 2
15 *
16 /
17 STO 17
18 1.5
19 X<>Y
20 X>Y?
21 GTO 05
22 RCL 17
23 1.3432
24 *
25 RCL 17
26 X↑2
27 -1.4569
28 *
29 +
30 RCL 17
31 3
32 Y↑X
33 .708
34 *
35 +
36 RCL 17
37 4
38 Y↑X
39 -.1276
40 *
41 +
42 .5147
43 +
44 STO 00
45 GTO 06

46♦LBL 05
47 1
48 STO 00

49♦LBL 06
50 RCL 25
51 X↑2
52 STO 32
53 RCL 10
54 2
55 /
56 RCL 11
57 /
58 PI
59 /
60 RCL 05
61 X↑2
62 /
63 SQRT
64 STO 20
65 X↑2
66 1/X
67 RCL 32
68 *
69 2
70 /
71 CHS
72 STO 34
73 X↑2
74 1
75 +
76 SQRT
77 RCL 34
78 +
79 SQRT
80 RCL 10
81 *
82 RCL 20
83 *
84 550
85 /
86 RCL 15
87 *
88 RCL 00
89 *
90 STO 16
91 "PI="
92 ARCL X
93 AVIEW
94 STOP
95 END
```

6. Profile power

a. PURPOSE

This subroutine calculates the profile power required for forward, straight and level flight in terms of horsepower.

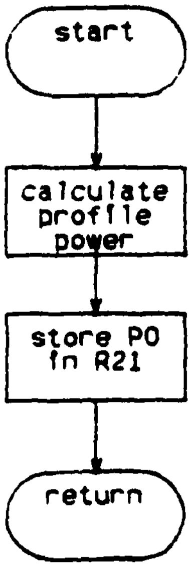
b. ASSUMPTIONS

Steady flow through the rotor sustem.

c. EQUATIONS

$$P_o = \frac{\sigma \, Cdo \, \rho \, A_o V_r^2 \, (1 + 4.25 \mu^2)}{4400} \quad \text{(hp)}$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINE USED

" WBS "

f. PROGRAM LISTING

```
01♦LBL "P01"
 02 RCL 19
 03 RCL 07
 04 *
 05 RCL 11
 06 *
 07 RCL 05
 08 X↑2
 09 *
 10 PI
 11 *
 12 RCL 13
 13 3
 14 Y↑X
 15 *
 16 8
 17 /
 18 STO 21
 19 RCL 24
 20 4.25
 21 *
 22 1
 23 +
 24 RCL 21
 25 *
 26 550
 27 /
 28 STO 21
 29 "P0="
 30 ARCL X
 31 AVIEW
 32 STOP
 33 END
```

7. Parasite Power

a. PUPOSE

This subroutine calculates the parasite power required in forward, straight and level flight.

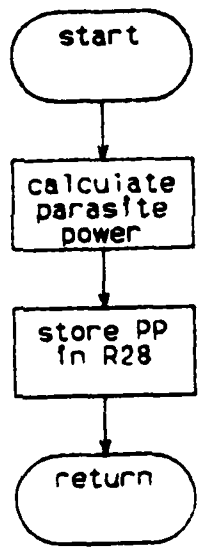
b. ASSUMPTIONS

Steady flow through the rotor system.

c. EQUATIONS

$$PP = \frac{\rho f V_F^3}{1100} \quad (hp)$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

" WBS "

f. PROGRAM LISTING

```
01♦LBL "PP1"
 02 RCL 11
 03 RCL 26
 04 *
 05 .5
 06 *
 07 RCL 25
 08 3
 09 Y↑X
 10 *
 11 550
 12 /
 13 STO 28
 14 "PP="
 15 ARCL X
 16 AVIEW
 17 STOP
 18 END
```

8. Maximum Forward Velocity

a. Purpose

This subroutine calculates the power-limited maximum speed of the specified helicopter.

b. ASSUMPTIONS

a. The power-limited maximum velocity may be estimated by neglecting the variatin of induced power and profile power with speed.

b. Power required to hover is approximately equal to power required fo maximum speed.

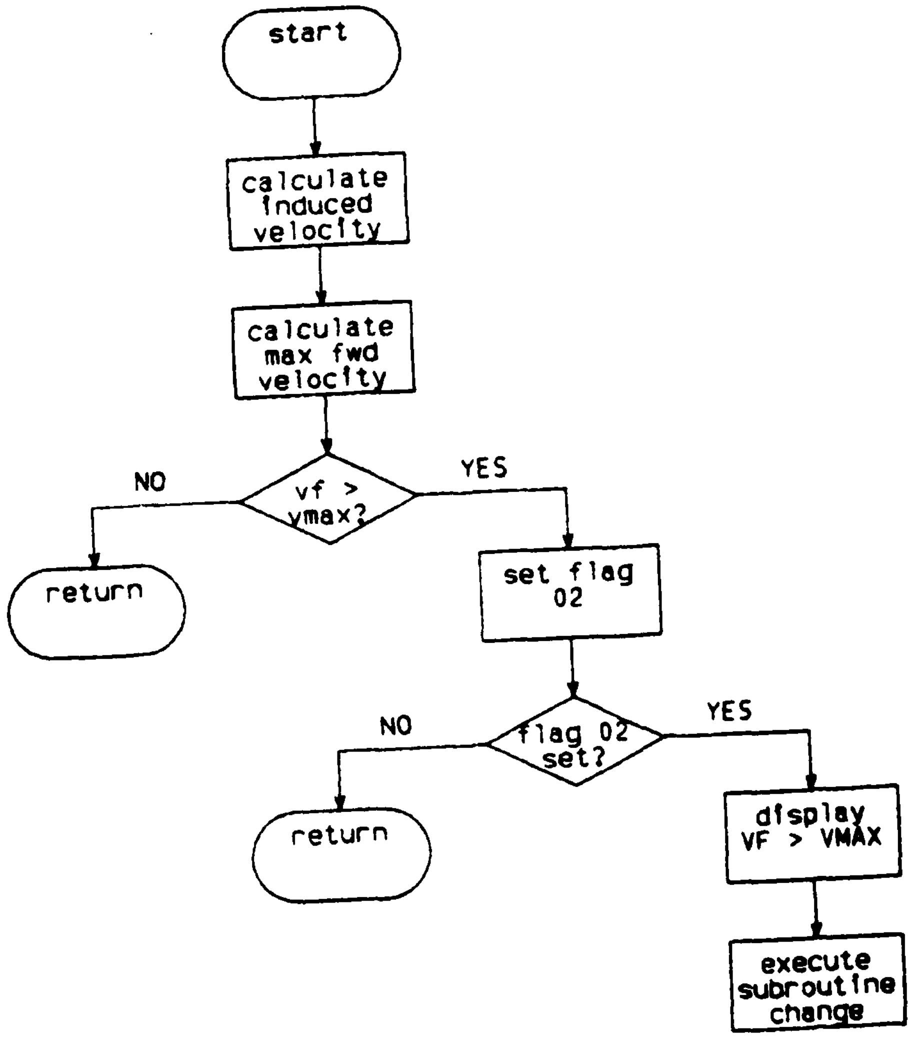
c. Steady flow through the rotor system.

c. EQUATIONS

$$VMAX = v_f \left[\frac{4}{f/A_b}\right]^{1/3}$$

$$v_f = \left[\frac{W}{2 \rho A_b}\right]^{1/2}$$

D. FLOWCHART


start
calculate induced velocity
calculate max fwd velocity
vf > vmax?
NO
YES
return
set flag 02
flag 02 set?
NO
YES
return
display VF > VMAX
execute subroutine change

e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
LBL "VMAX"
RCL 26
PI
/
RCL 05
X↑2
/
1/X
4
*
.3333334
Y↑X
RCL 20
*
STO 01
1.6884
/
"VMAX="
ARCL X
AVIEW
STOP
RCL 01
RCL 25
X>Y?
GTO 12
X<=Y?
GTO 13

LBL 12
"VF > VMAX"
AVIEW
XEQ "CNG"

LBL 13
END
```

9. Best Endurance Velocity

A. PURPOSE

To calculate the value of velocity corresponding to minimum power (i.e., best endurance velocity and/or best rate of climb).

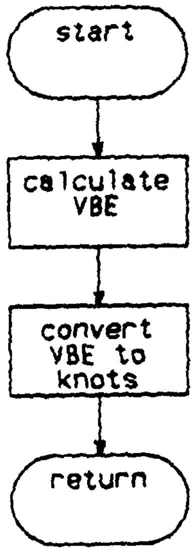
B. ASSUMPTIONS

1. Steady flow through the rotor system.
2. The variation of profile power with forward velocity is negligible.

C. EQUATIONS

$$V_{BE} = \left[\frac{W}{\rho * A} * \left(\frac{A}{3 * f}\right)^{1/2} \right]^{1/2} \quad \text{(ft/s)}$$

D. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

" WBS "

f. PROGRAM LISTING

```
01*LBL "VBE"
02 RCL 05
03 X↑2
04 PI
05 *
06 3
07 /
08 RCL 26
09 /
10 SQRT
11 RCL 10
12 *
13 RCL 11
14 /
15 RCL 05
16 X↑2
17 /
18 PI
19 /
20 SQRT
21 1.68894
22 /
23 "VBEK="
24 ARCL X
25 AVIEW
26 STOP
27 END
```

10. Stall Onset Velocity

a. PURPOSE

This subroutine gives the user of the HP 41-CV an initial approximation for the velocity at which the retreating blade angle of attack is approximately equal to the is approximately equal to the static stall angle of the rotor blade.

b. ASSUMPTIONS

1. Steady flow through the rotor system.
2. Stall onset velocity is approximately equal to the velocity for best range (i.e., minimum P/V).

c. EQUATIONS

$$p = (-4.25\,\sigma\,Cdo\ A_D V_T\ )/(4f)$$

$$r = (-\sigma\ Cdo\ A_D\ V_T^3)/(4f)$$

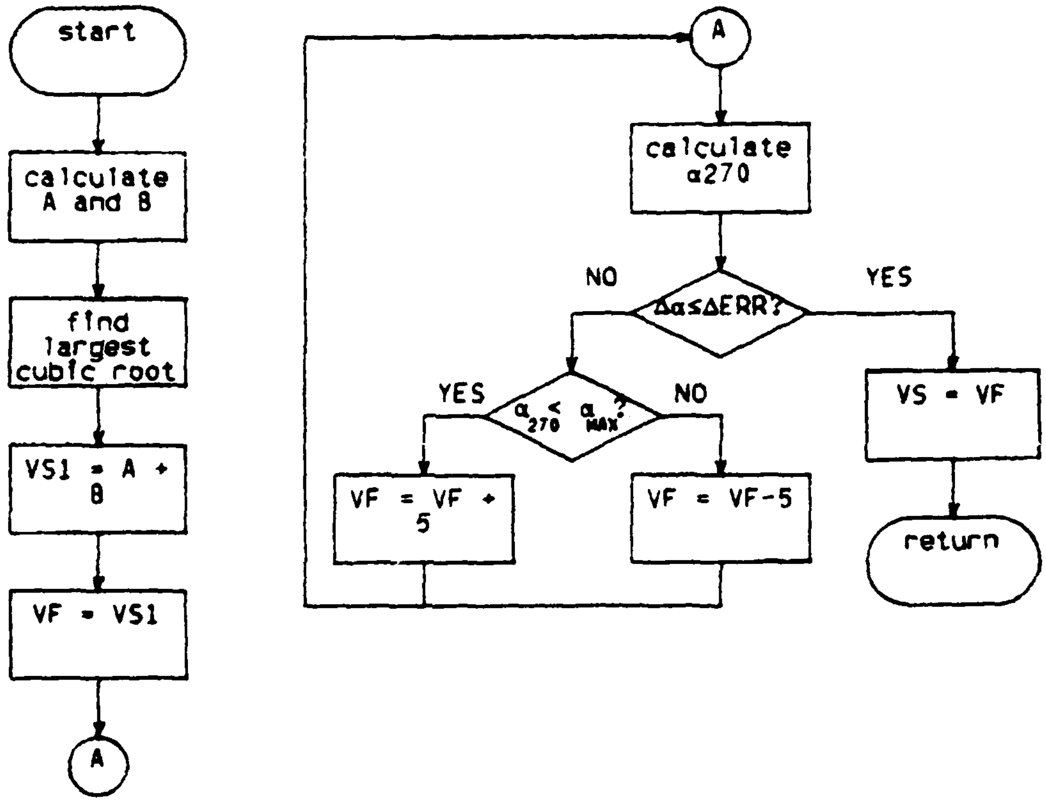
$$a = -1/3 * p^2$$

$$b = 1/27 * (2 * p^2 + 27 * r)$$

$$A = [\ -b/2 + (b^2/2 + a^3/27)^{1/2}]^{1/3}$$

$$B = [\ -b/2 - (b^2/2 + a^3/27)^{1/2}]^{1/3}$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

" WBS "

f. PROGRAM LISTING

```
01♦LBL "VS"
02 FS? 03
03 GTO 10
04 RCL 19
05 RCL 07
06 *
07 PI
08 *
09 RCL 05
10 X↑2
11 *
12 4
13 /
14 RCL 26
15 /
16 STO 03
17 RCL 13
18 *
19 4.25
20 *
21 CHS
22 STO 01
23 RCL 13
24 3
25 Y↑X
26 RCL 03
27 *
28 CHS
29 STO 02
30 27
31 *
32 RCL 01
33 3
34 Y↑X
35 2
36 *
37 +
38 27
39 /
40 STO 31
41 RCL 01
42 X↑2
43 -3
44 1/X
45 *
46 STO 30
47 RCL 31
48 X↑2
49 4
50 /
51 RCL 30
52 3
53 Y↑X
54 27
55 /
56 +
57 SQRT
58 STO 33
59 RCL 31
60 CHS
61 2
62 /
63 +
64 .333334
65 Y↑X
66 STO 32
67 RCL 31
68 CHS
69 2
70 /
71 RCL 33
72 -
73 .333334
74 Y↑X
75 STO 34
76 RCL 32
77 +
78 STO 02
79 .25
80 *
81 RCL 02
82 +
83 STO 25
84 SF 03
85 GTO "AGN"

86♦LBL 10
87 RCL 27
88 RCL 12
89 /
90 STO 31
91 RCL 41
92 -
93 X↑2
94 SQRT
95 .001
96 X<>Y
97 X<=Y?
98 GTO 11
99 RCL 31
100 RCL 41
101 X>Y?
102 GTO 12
103 RCL 41
104 RCL 31
105 X>Y?
106 GTO 13

107♦LBL 12
108 RCL 25
109 5
110 -
111 STO 25
112 GTO "AGN"

113♦LBL 13
114 RCL 25
115 5
116 +
117 STO 25
118 GTO "AGN"

119♦LBL 11
120 CF 03
121 RCL 41
122 R-D
123 "∡STALL="
124 ARCL X
125 AVIEW
126 STOP
127 RCL 25
128 1.68894
129 /
130 "VS="
131 ARCL X
132 AVIEW
133 STOP
134 END
```

11. Inflow Ratio

(a) PURPOSE

This subroutine calculates the ratio of the net velocity up through the rotor system to the tip speed.

(b) ASSUMPTIONS

Steady flow through the rotor system.

(c) EQUATIONS

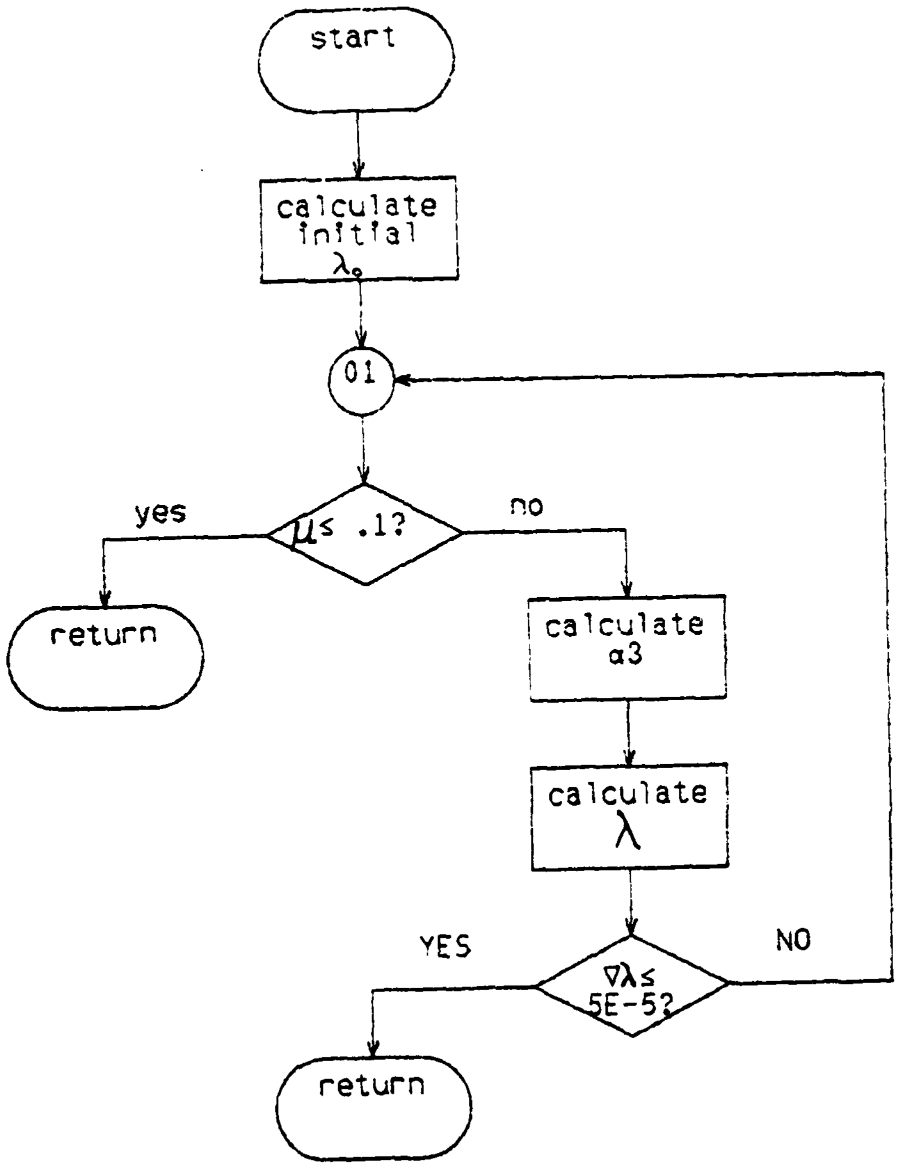
$$\lambda = -\sqrt{CT/2}$$

$$\lambda = -\frac{CT}{2\sqrt{\lambda^2 + \mu^2}} + \mu \operatorname{Tan} \alpha_3$$

$$D_P = (PP*550)/V_F$$

$$\alpha_3 = -\operatorname{Tan}(D_P/W)$$

d. FLOWCHART


start
calculate initial λ_0
01
$\mu \leq .1$?
yes
no
return
calculate $\alpha 3$
calculate λ
YES
NO
$\nabla\lambda \leq$ 5E-5?
return

e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01♦LBL "LAMB"
02 RCL 14
03 2
04 /
05 SQRT
06 CHS
07 STO 03
08 .1
09 RCL 22
10 X<=Y?
11 GTO 06
12 RCL 28
13 550
14 *
15 RCL 25
16 /
17 RCL 10
18 /
19 STO 23

20♦LBL 01
21 RCL 14
22 CHS
23 RCL 03
24 X↑2
25 RCL 24
26 +
27 SQRT
28 2
29 *
30 /
31 ENTER↑
32 RCL 23
33 R-D
34 TAN
35 RCL 22
36 *
37 -
38 STO 08
39 RCL 03
40 -
41 X↑2
42 SQRT
43 .00005
44 X>Y?
45 GTO 02
46 RCL 08
47 STO 03
48 GTO 01

49♦LBL 02
50 RCL 08
51 STO 03

52♦LBL 06
53 END
```

12. Angle of Attack at 90 Degrees

a. PURPOSE

This subroutine calculates the angle of attack at the azimuthal position of 90 degrees.

b. ASSUMPTIONS

a. Steady flow through the rotor system.

b. Blade oscillations are periodic in nature.

c. Only first harmonics of flapping are necessary for calculating angle of attack.

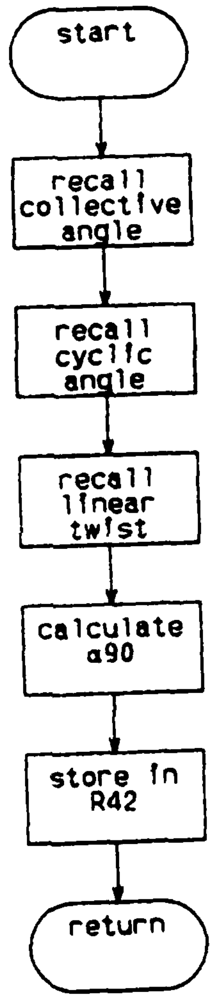
d. The thrust vector passes through the C.G.

e. Only uniform twist of the rotor blade is possible.

c. EQUATIONS

$$\alpha 90 = \Theta_0 + \Theta_2 + \Theta_T + \frac{\lambda}{(1 + \mu)}$$

d. FLOWCHART


start
recall collective angle
recall cyclic angle
recall linear twist
calculate α90
store in R42
return

e. PROGRAMS AND SUBROUTINES USED

" W8S "

" α90 "

f. PROGRAM LISTING

```
01♦LBL "∡90"
 02 RCL 33
 03 RCL 32
 04 +
 05 RCL 29
 06 +
 07 ENTER↑
 08 RCL 03
 09 1
 10 RCL 32
 11 +
 12 /
 13 +
 14 STO 42
 15 R-D
 16 "∡90D="
 17 ARCL X
 18 AVIEW
 19 STOP
 20 END
```

13. Compressibility Power

a. PURPOSE

This subroutine calculates the power required due to com_ pressibility on the main rotor sustem in forward,straight and level flight in terms of horsepower.

2. ASSUMPTIONS

a. Steady flow through the rotor system.

b. The compressibility losses can be expressed as a function of the amount by which the drag divergence Mach nunber is exceeded at the tip of the advancing blade.

c. EQUATIONS

$$M_{tip} = \frac{V_f + V_t}{a_s}$$

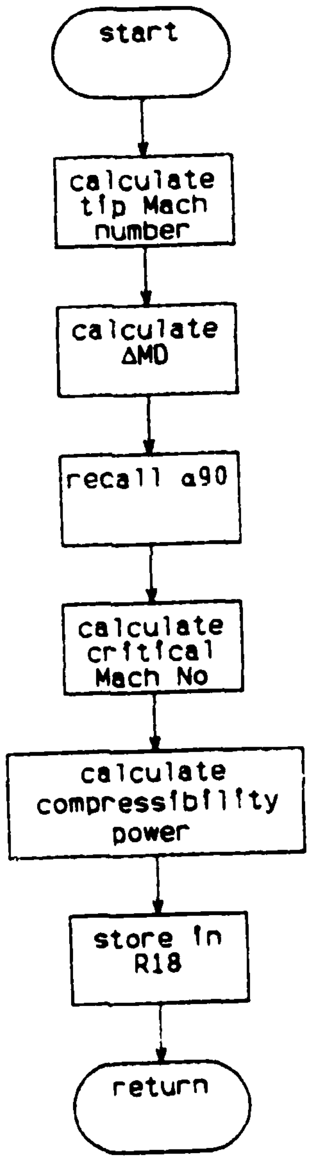
$$\Delta M_d = M_t - M_{crit} \quad 0.06$$

$$M_{crit} = 0.71 - 2.3 * \alpha 90$$

$$C_{pc} = \quad * [0.012 * \Delta M_d + 0.1 * (\Delta M_d)^3]$$

$$P_M = \frac{C_{pc} * \rho * PI * R^2 * V_t^3}{550} \quad (\text{ HP })$$

d. FLOWCHART


start
calculate tip Mach number
calculate ΔMD
recall α90
calculate critical Mach No
calculate compressibility power
store in R18
return

f. PROGRAM LISTING

```
01♦LBL "CPC"
02 RCL 13
03 RCL 25
04 +
05 RCL 43
06 /
07 STO 31
08 RCL 42
09 RCL 12
10 *
11 .113
12 *
13 CHS
14 RCL 44
15 +
16 STO 32
17 CHS
18 RCL 31
19 +
20 .06
21 -
22 STO 33
23 0
24 X<>Y
25 X<=Y?
26 GTO 09
27 RCL 33
28 3
29 Y↑X
30 .1
31 *
32 ENTER↑
33 RCL 33
34 .012
35 *
36 +
37 RCL 19
38 *
39 STO 34
40 RCL 11
41 *
42 RCL 05
43 X↑2
44 *
45 PI
46 *
47 ENTER↑
48 RCL 13
49 3
50 Y↑X
51 *
52 550
53 /
54 STO 18
55 GTO 10

56♦LBL 09
57 0
58 STO 18

59♦LBL 10
60 "PC="
61 ARCL X
62 AVIEW
63 STOP
64 END
```

14. Stall Power

a. PURPOSE

This subroutine estimates the additional power required in forward, straight and level flight due to retreating blade stall. Additionally, this subroutine calculates a stall correction factor, k_s that corrects for the special case of inboard stalling.

b. ASSUMPTIONS

a. Steady flow through the rotor system.

b. The section drag coefficient at stall jumps approximately 0.08 at stall onset.

c. The stalled area is symmetric about the 270 degree azimuthal position.

d. For all airfoils considered, the static stall angle is approximately 12.5 degrees.

c. EQUATIONS

$$\frac{-B_s}{2 * \theta_T} \leq 1.0$$

where,

$$B_s = -\mu * \theta_T - \Gamma$$

$$\Gamma = 0.218166 - \theta_o + \theta_2$$

$$k_s = -\left(\frac{B_s / 2 * \theta_T + X_s}{1 - X_s} \right)$$

$$C_{ps} = \left[\frac{\sigma}{24 * pi} * (1 - \mu)^2 * (1 - X_s) * (1 - X_s^2)^{1/2} \right]$$

$$P_s = C_{ps} * \rho * PI * R^2 * V_T^3$$

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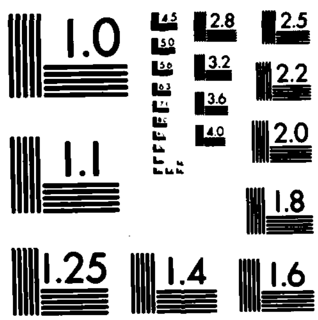
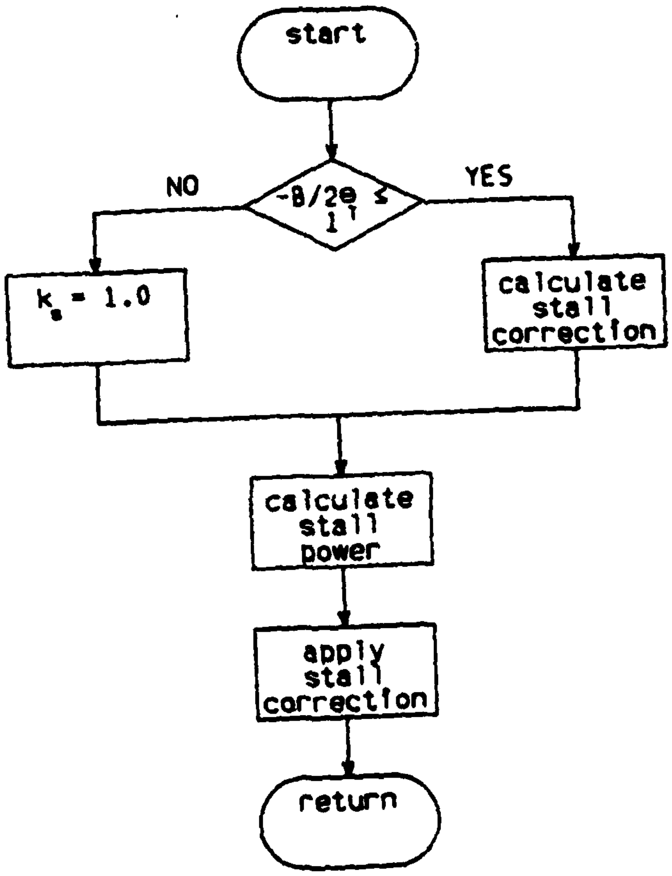

1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

" WBS "

" SD "

" CT "

" W "

" PP1 "

" LAMB "

f. PROGRAM LISTING

```
01♦LBL "CPS"
02 FS? 01
03 GTO 06
04 RCL 30
05 RCL 08
06 +
07 2
08 /
09 1
10 X<>Y
11 X<=Y?
12 GTO 01
13 1
14 STO 23
15 GTO 02

16♦LBL 01
17 RCL 31
18 2
19 /
20 RCL 29
21 /
22 RCL 30
23 +
24 CHS
25 ENTER↑
26 1
27 RCL 30
28 -
29 /
30 STO 23

31♦LBL 02
32 "KS="
33 ARCL X
34 AVIEW
35 STOP
36 SF 02
37 RCL 19
38 24
39 /
40 PI
41 /
42 ENTER↑
43 1
44 RCL 22
45 -
46 X↑2
47 *
48 1
49 RCL 30
50 -
51 *
52 1
53 RCL 30
54 X↑2
55 -
56 SQRT
57 *
58 RCL 23
59 *
60 STO 23
61 RCL 13
62 3
63 Y↑X
64 RCL 23
65 *
66 PI
67 *
68 RCL 05
69 X↑2
70 *
71 RCL 11
72 *
73 550
74 /
75 STO 23
76 FS? 02
77 GTO 07

78♦LBL 06
79 0
80 STO 23

81♦LBL 07
82 "PS="
83 ARCL X
84 AVIEW
85 STOP
86 END
```

15. <u>Total Power</u>

a. PURPOSE

This subroutine calculates the total power required in forward, straight and level flight, to include stall and compressibility power in terms of hosepower.

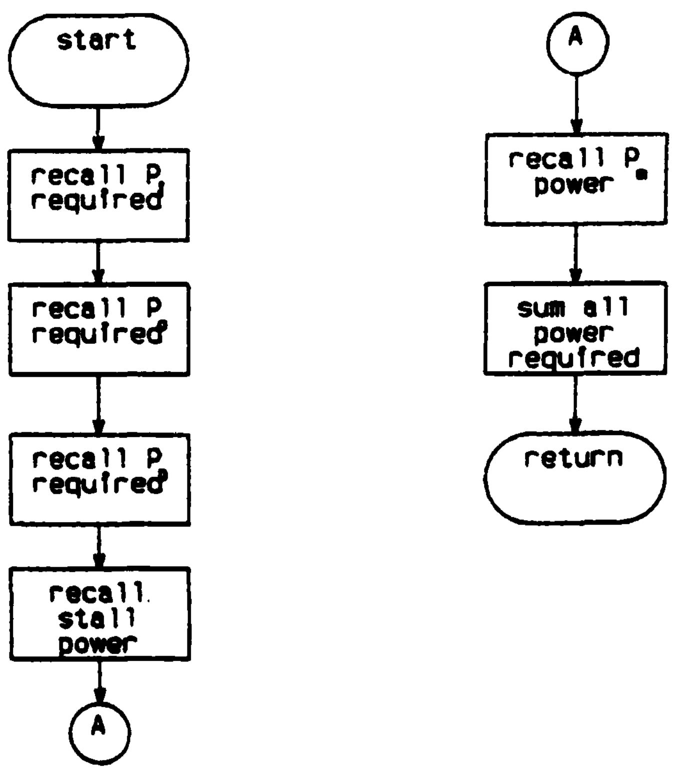
c. ASSUMPTIONS

Power losses, such as transmission and cooling, can be ignored.

c. EQUATIONS

$$P_T = P_i + P_o + P_p + P_s + P_M$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01♦LBL "PT1"
 02 RCL 20
 03 RCL 16
 04 +
 05 RCL 21
 06 +
 07 RCL 23
 08 +
 09 RCL 18
 10 +
 11 "PT="
 12 ARCL X
 13 AVIEW
 14 STOP
 15 END
```

16. Density/Sonic Velocity

a. PURPOSE

To generate values of air density and sonic velocity.

b. ASSUMPTIONS

(1) Geopotential altitude (H), and geometric altitudes are equal below 20,000 feet (actual ΔH = 29 ft).

(2) In the troposphere the standard temperature lapse rate is -3.57 °F per 1000 feet.

c. EQUATIONS

$$\theta = T/T_{SSL} = (1.0 - 6.8753\ E{-}06 * H)$$

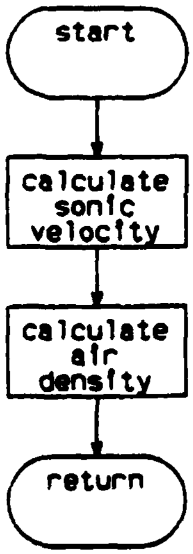
$$SVEL = SVEL_{SSL} * SQRT(\theta)$$

$$RHO = 0.0023769 * (1.0 + HTH * (-.02875 + 0.000275 * HTH)$$

where,

$$HTH = DA/1000$$

d. FLOWCHART



e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01*LBL "DEN"
02 RCL 45
03 6.875 E-06
04 *
05 CHS
06 1
07 +
08 SQRT
09 1116.89
10 *
11 STO 43
12 RCL 45
13 1000
14 /
15 STO 33
16 .000275
17 *
18 -.02875
19 +
20 RCL 33
21 *
22 1
23 +
24 .0023769
25 *
26 STO 11
27 END
```

17. Change

a. PURPOSE

This subroutine is used to expedite the changing of up to five of the input parameters whenever a design restraint is exceeded and/or at the end of the main program.

b. ASSUMPTIONS

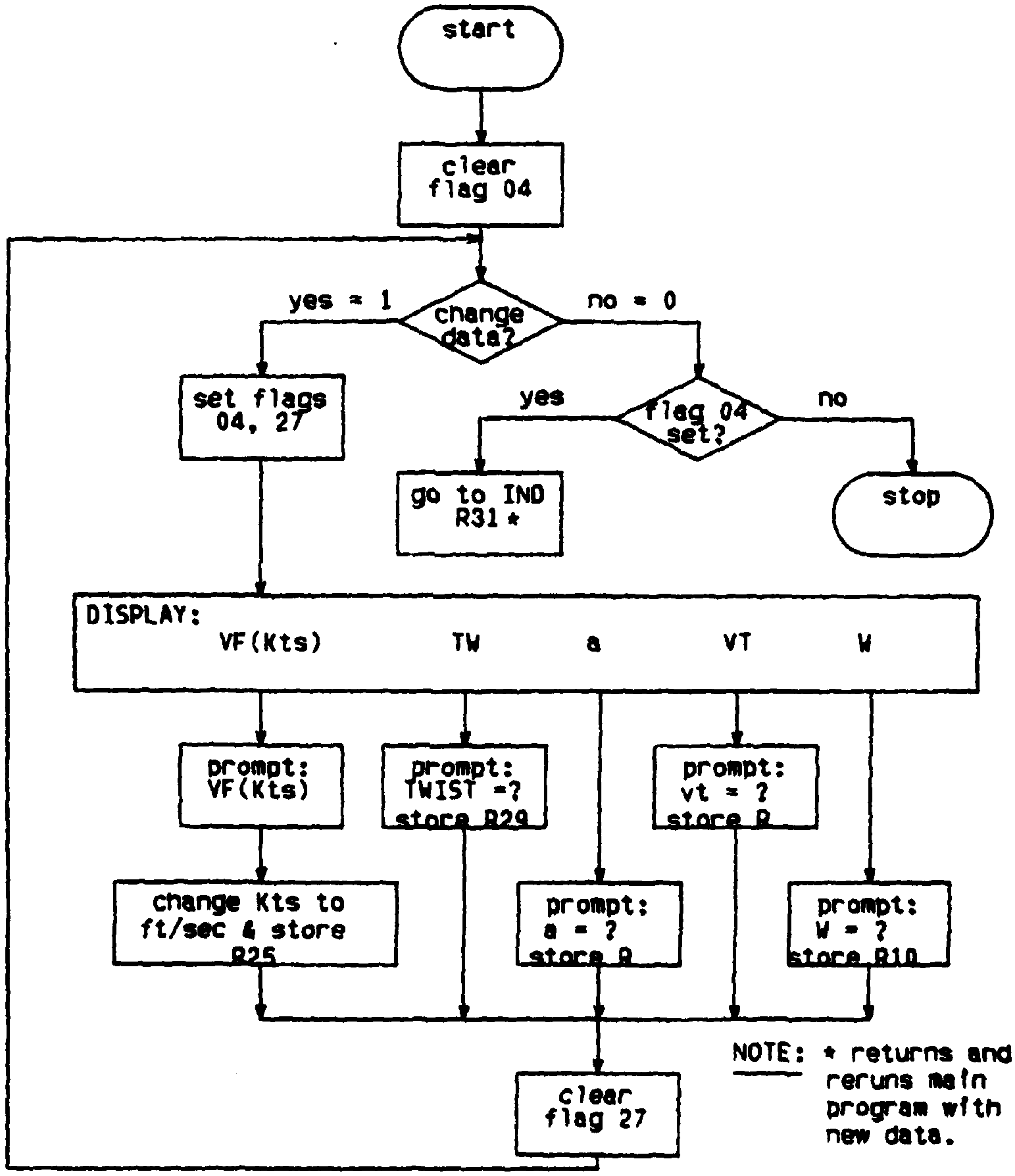
The primary parameters which will require changing are:

a.	Forward velocity, VF;	(Kts)
b.	blade twist, TW;	(rads)
c.	lift curve slope, a;	(per rad)
d.	tip velocity, VT;	(ft/sec)
e.	weight, W;	(lbs)

c. EQUATIONS

$$VF\ (ft/sec) = VF\ (Kts) * 1.68894 \quad .$$

d. FLOWCHART


start
clear flag 04
change data?
yes = 1
no = 0
set flags 04, 27
flag 04 set?
yes
no
go to IND R31 *
stop
DISPLAY:
VF(Kts)
TW
a
VT
W
prompt: VF(Kts)
prompt: TWIST =? store R29
prompt: vt = ? store R
change Kts to ft/sec & store R25
prompt: a = ? store R
prompt: W = ? store R10
clear flag 27
NOTE: * returns and reruns main program with new data.

e. PROGRAMS AND SUBROUTINES USED

' WBS '

f. PROGRAM LISTING

```
01♦LBL "CNG"
02 "AGN"
03 ASTO 31
04 CF 04

05♦LBL 06
06 "CHANGE?"
07 PROMPT
08 X=0?
09 GTO 07
10 SF 04
11 SF 27
12 "VF TW a VT W"
13 PROMPT

14♦LBL A
15 "VF(KTS)=?"
16 PROMPT
17 1.68894
18 *
19 STO 25
20 GTO 05

21♦LBL B
22 "TWIST=?"
23 PROMPT
24 STO 29
25 GTO 05

26♦LBL C
27 "a=?"
28 PROMPT
29 STO 60
30 GTO 05

31♦LBL D
32 "VT=?"
33 PROMPT
34 STO 13
35 GTO 05

36♦LBL E
37 "W=?"
38 PROMPT
39 STO 10

40♦LBL 05
41 CF 27
42 GTO 06

43♦LBL 07
44 FS? 04
45 GTO IND 31
46 END
```

D. HP 41-CV SAMPLE OUTPUT

Depending on the value of forward velocity there are three possible types of output that the HP 41-CV computer program is capable of producing. Examples of the three possible cases are listed below.

CASE 1 : Forward velocity, VF, is less than stall onset velocity.

```
PI=791.751153
PO=224.504453
PP=0.000000

VS=137.762848
VBEK=76.060750
VMAX=163.448330

CYCLIC=0.000000
COLL=17.896907

∡270=4.880790

∡90D=4.880790

PS=0.000000

PM=0.000000

PT=1,016.255606
```

CASE 2 : Forward velocity, VF, is greater than stall onset velocity.

PI=113.87
PO=352.43
PP=704.24

VS=137.76
VBEK=76.06
VMAX=163.45

CYCLIC=-9.39
COLL=20.76

∡270=17.75

∡90D=-1.03

XS=0.74
XO=1.24

KS=0.96
PS=148.90

PM=253.71

PT=1,573.16

CASE 3 : Forward velocity, VF, is greater than the maximum forward velocity possible.

```
PI=107.18
PO=368.92
PP=844.72

VS=137.76
VBEK=76.06
VMAX=163.45
VF > VMAX

CYCLIC=-10.55
COLL=22.08

∠270=19.87

∠90D=-1.23

XS=0.73
XO=1.53

KS=1.00
PS=156.10

PM=289.23

PT=1,766.15
```

APPENDIX C

A. IBM 3033 PROGRAM DOCUMENTATION

This program calculates the power required to fly a helicopter in forward, straight and level high speed flight. In the sections that follow all inputs and implementation requirements are specified. The problem solving methodology used is as described in Chapter II.

B. INPUT DATA REQUIRED

In calculating the performance of a helicopter it is necessary to define a set of force conditions, environmental conditions, and physical conditions. The force conditions required are the aircraft gross weight (W) in pounds, the maximum lift coefficient (CLMAX), and the the coefficient of list at zero angle of attack (CDO). The environmental conditons include, forward velocity (VFK) in knots, speed of sound (SVEL) in feet/sec, rotor height above the ground (H) in feet, and air density (RHO) in lb-ft /sec . For sake of user simplicity, the the speed of sound and air density are generated within the program and are comparable to the values found in a standard atmosphere table. Finally, the physical conditions required are the rotor radius (R) in feet, tip velocity (VT) in ft/sec, number of blades (b), main rotor chord (C) in feet, flat plate area (FPA) in ft , geometric twist of the rotor (TWIST) in radians, and airfoil lisft curve slope (CLA) in per radians.

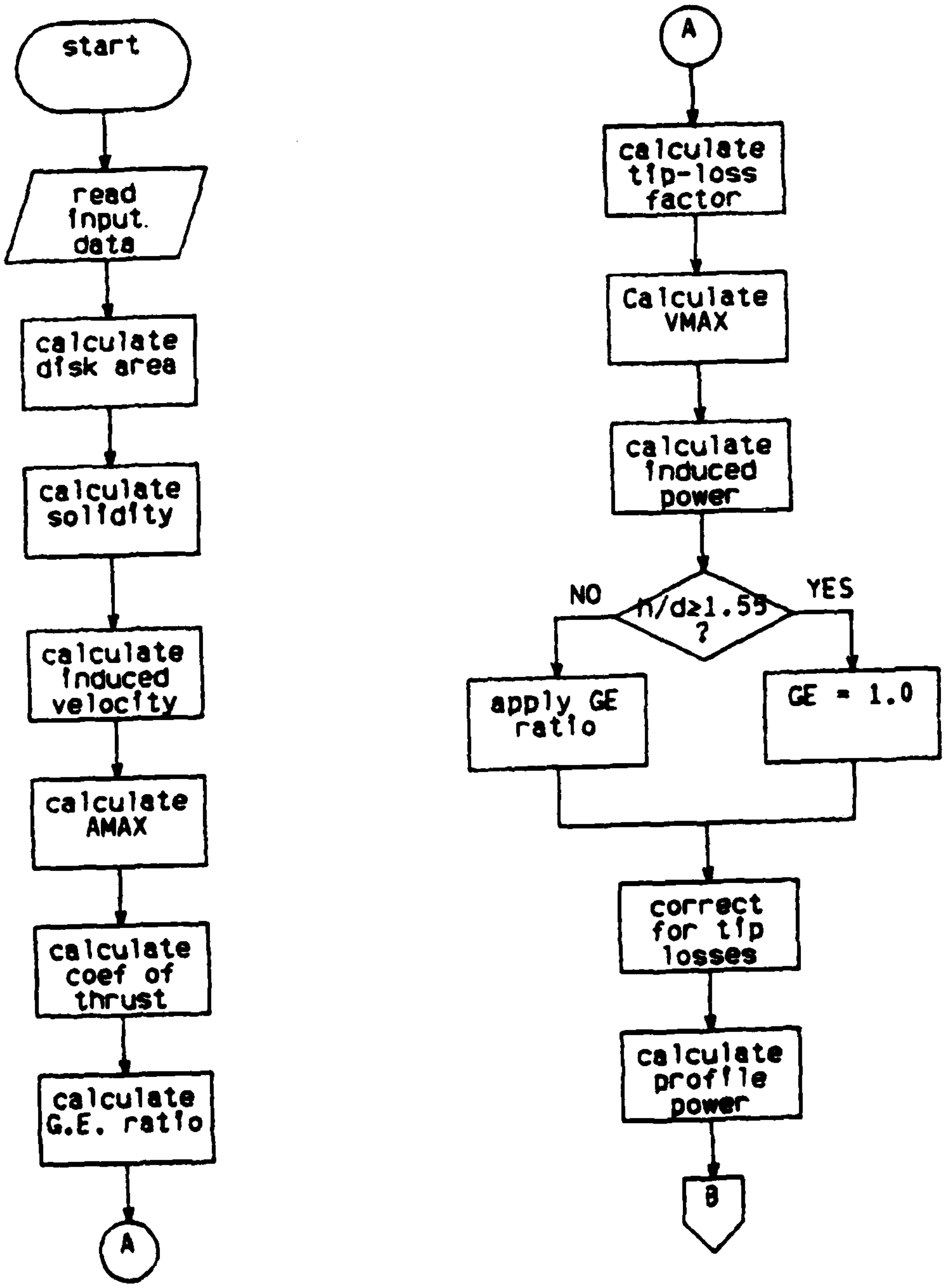
C. HELICOPTER SAMPLE DATA

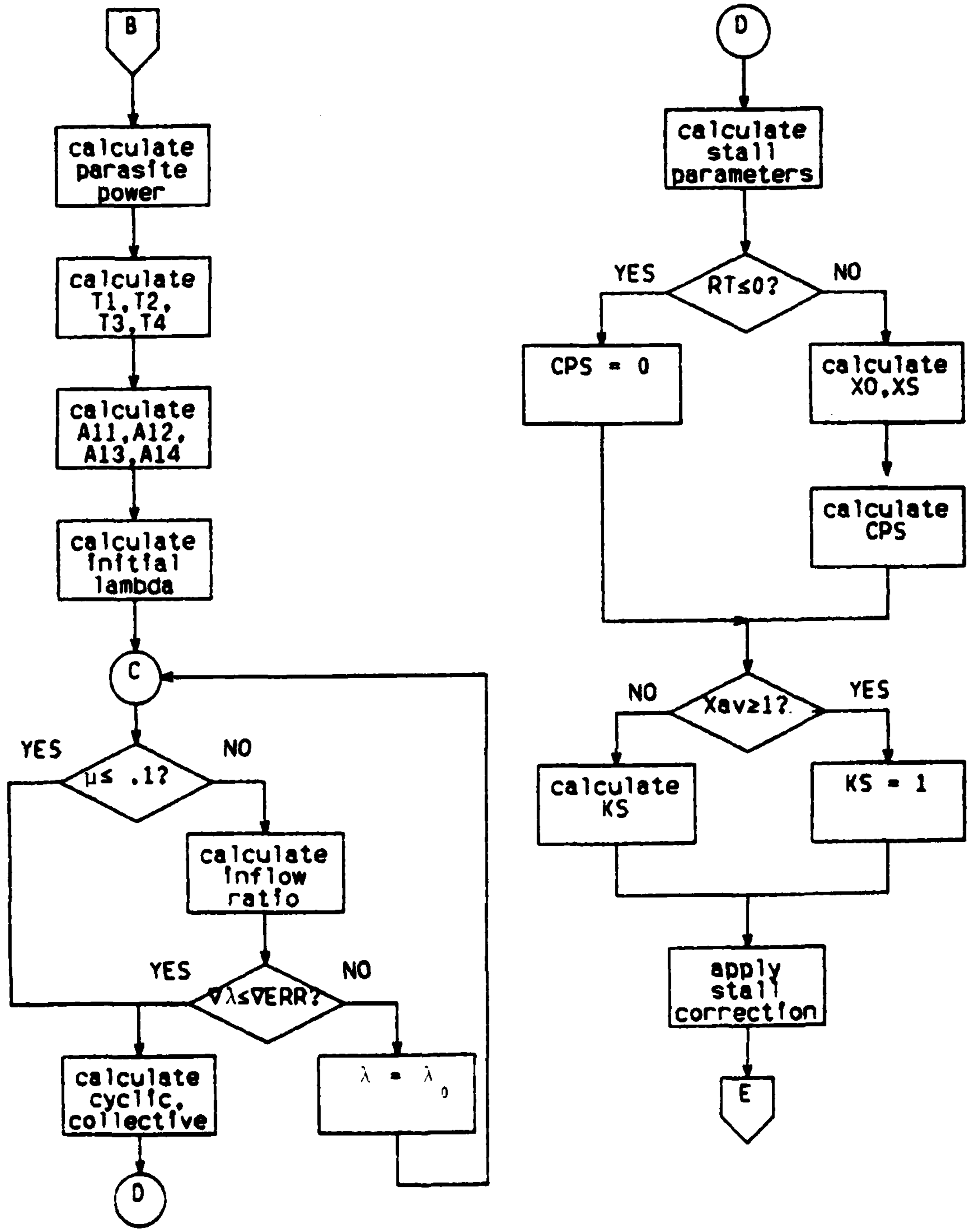
Table C.1 below illustrates the format required when inputing data.

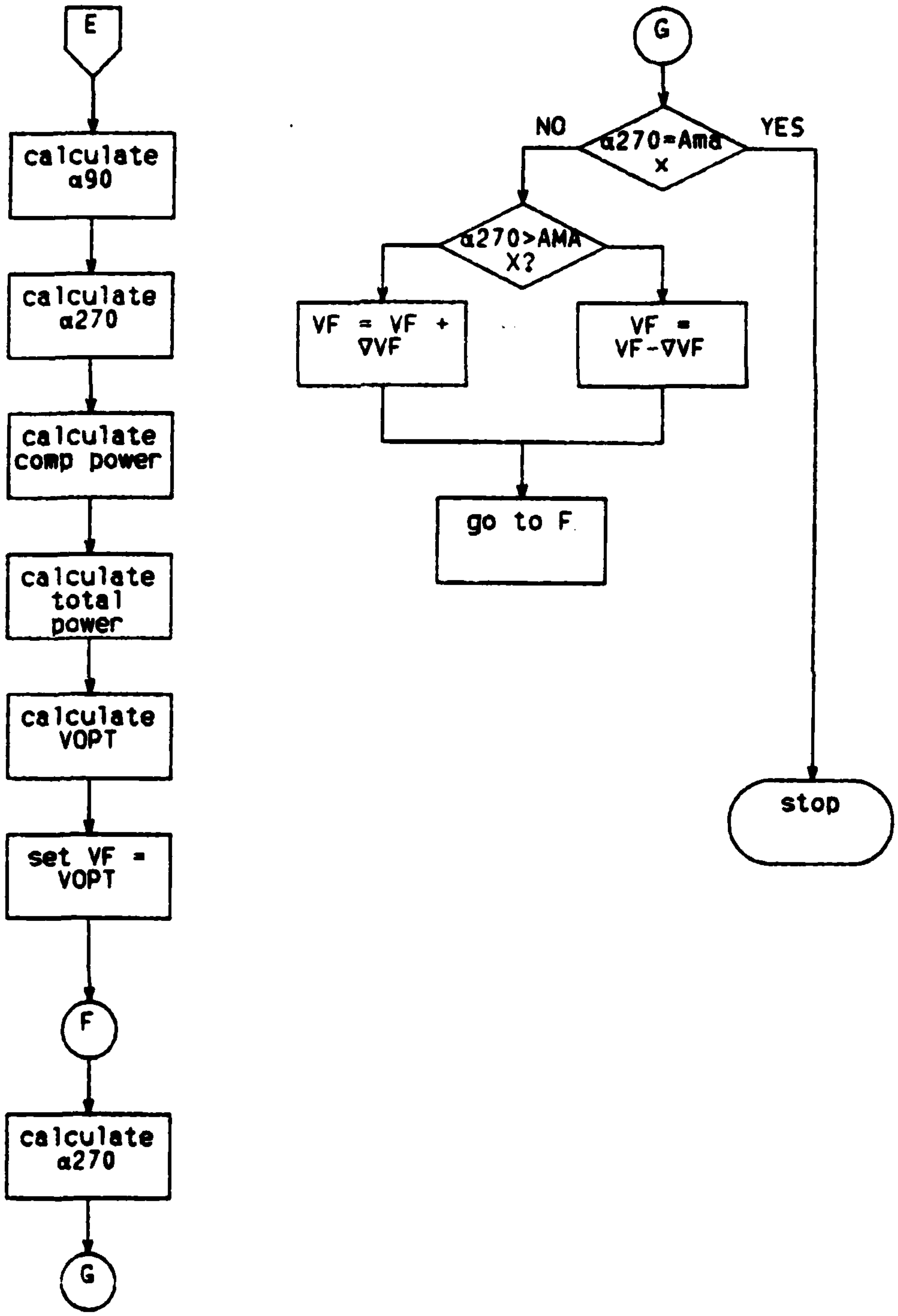
TABLE C.1 HELICOPTER SAMPLE INPUT DATA

RADIUS	CDO	W	VT	FPA
22.	.01075	10512.	738.0	17.
TWIST	NO. BLADES	CHORD	INITIAL VFK	CLA
-.1745	2.	2.25	0.0	5.73
H	CLMAX	NO. ENGINES	TYPE AIRFOIL	DA
1000.	1.4	2.	7.	1000.

D. IBM PROGRAM FLOWCHART




B
calculate parasite power
calculate T1,T2, T3,T4
calculate A11,A12, A13,A14
calculate initial lambda
C
YES
NO
μ≤ .1?
calculate inflow ratio
YES
NO
∇λ≤∇ERR?
calculate cyclic, collective
λ = λ0
D
D
calculate stall parameters
YES
RT≤0?
NO
CPS = 0
calculate XO,XS
calculate CPS
NO
Xav≥1?
YES
calculate KS
KS = 1
apply stall correction
E


E
calculate α90
calculate α270
calculate comp power
calculate total power
calculate VOPT
set VF = VOPT
F
calculate α270
G
G
α270=Amax
NO
YES
α270>AMAX?
VF = VF + ∇VF
VF = VF-∇VF
go to F
stop

E. IBM PROGRAM LISTING

This section contains the listing of the IBM 3033 computer program developed in this report.

```
C
C     THIS PRCGRAM CLACULATES THE PERFORMANCE OF A HELICOPTER
C     FROM HOVER TO FCRWARD, STRAIGHT AND LEVEL FLIGHT, HIGH
C     SPEED FIGHT.
C
C            WRITTEN BY   CPT W. CARMONA (JUN 83)
C
      INTEGER NDEG,IER/0/,CENT/0/
      REAL LAMBDA,MU,KS,K,MCRIT,MT,H,N,LERR,MCRO,LAMBD1,HTH,MCRITO
      DATA DERR/.C01/,NDEG/3/,LERR/.0001/,MCRITO/0.725/,DVFK/10./
      READ(5,200)R,CDC,W,VT,FPA,TWIST,B,C,VFK,CLA,H,CLMAX,N,TYPE,DA
      WRITE(6,202)
      WRITE(6,201)
C
C*******************************************************************
C*    CALCULATION OF SONIC VELOCITY AND AIR DENSITY BASE ON STANDARD   *
C*                ATMOSPHERE TABLE                                      *
C*******************************************************************
C
      THETA = 1. - 6.8753 E-06 * H
      SVEL = 1116.89 * SQRT(THETA)
      HTH = DA/1000.
      RHO = 0.0023769 * (1. + HTH*(-.02875 + .000275 * HTH))
C
C*******************************************************************
C*    SELECTICN OF PROPER AIRFOIL DATA FOR TYPE OF AIRFOIL CHOSEN     *
C*******************************************************************
C
      IF(TYPE .EQ. 1)GO TC  1
      IF(TYPE .EQ. 2)GO TO  2
      IF(TYPE .EC. 3)GO TC  3
      IF(TYFE .EC. 4)GO TC  4
      IF(TYPE .EQ. 5)GO TO  5
      IF(TYPE .EQ. 6)GO TC  6
      IF(TYPE .EQ. 7)GO TO  7
C
C     NACA 0015 AIRFOIL CHARACTERISTICS
C
    1 MCRO = C.64
      CLMAX = 1.26
      CLA = 5.73
      GO TO  8
C
C     SC1095  AIRFOIL CHARACTERISTICS
C
    2 MCRO = C.73
      CLMAX = 1.16
      CLA = 5.73
```

```
      GO TO  8
C
C     NACA 63 A 410.5 AIRFOIL CHARACTERISTICS
C
    3 MCRO = C.72
      CLMAX = 1.37
      CLA = 6.25
      GO TO  8
C
C     NACA 0012 AIRFOIL CHARACTERISTICS
C
    4 MCRO = C.72
      CLMAX = 1.25
      CLA = 5.73
      GO TO  8
C
C     NACA 0010 AIRFOIL CHARACTERISTICS
C
    5 MCRO =0.74
      CLMAX = 1.22
      CLA =  5.8
      GO TO  8
C
C     NACA 0011 AIRFOIL CHARACTERISTICS
C
    6 MCRO = 0.73
      CLMAX =  1.2
      CLA = 5.73
      GO TO  8
C
C     AH1-J CCBRA AIRFOIL CHARACTERISTICS
C
    7 MCRO = C.72
      CLMAX = 1.4
      CLA = 5.73
  8   AMAX = CLMAX/CLA
      WRITE(6,312)R,C,B,W,VT,FPA,N,DA,H,RHO,SVEL,TWIST,TYPE,CLMAX,AMAX,
     >         CLA,CDO,MCRO,VFK
      PI = 3.1459
      AD = PI * (R**2)
      SD = (B * C)/(PI * R)
      VI = SGRT(W/(2.*RHO*AD))
      CT = W/(AD * RHO * (VT**2))
      D = 2 * R
      GE = -.1276*(H/D)**4+.708*(H/D)**3-1.4569*(H/D)**2+1.3432*(H/D)
     >      +.5147
      IF (H/C .GT. 1.55)GE = 1.0
      BTL = 1.0 - (SQRT(2.*CT)/B)
```

```
      WRITE(6,310)CT,VI,AD,SD,BTL,GE
C     IF (N .GE. 2.)N = (N - .30*N)
      VMAX = SQRT(W/2./RHO/AD)*(4./(FPA/AD))**.333334
      VMAXK = VMAX/1.68894
65    WRITE(6,236)VFK
      VF = VFK * 1.68894
      MU = VF/VT
C
C**********************************************************************
C*    BASIC POWER CALCULATIONS                                        *
C**********************************************************************
C
      VL = VF**2/(2.*VI**2)
      PIT = (1./BTL)*(GE)*SQRT(-VL+SQRT(VL**2+1.))*W*VI/550.
      PO = (SC*RHO*CDO*AD*(VT**3))*(1.+4.25*MU**2)/4400.
      PP = (.5 * RHO * FPA * (VF**3))/550.
      PT = PO + PIT + PP
C
C**********************************************************************
C* CALCULATING DYNAMIC PARAMETERS FOR CYCLIC AND COLLECTIVE ANGLES    *
C**********************************************************************
C
      C1 = (BTL**2 + .5 * MU**2)
      C2 = (BTL**2 - .5 * MU**2)
      T1 = .5 * C1
      T2 = (BTL**3)/3. + (MU**2 * BTL * .5)
      T3 = (BTL**2/4.) * (BTL**2 + MU**2)
      T4 = (MU/2.) * (BTL **2 + MU**2/4.)
      A11 = ((BTL**2*MU*.5 - (MU**3/8.))*4.)/(BTL**2*C2)
      A12 = (8.*MU*BTL)/(3.*C2)
      A13 = (2.*MU*BTL**2)/C2
      A14 = (BTL**2 + 1.5*MU**2)/C2
C
C**********************************************************************
C*    CALCULATION OF INFLOW ANGLE LAMBDA                              *
C**********************************************************************
C
      IF (VF .GT. 0.0) GO TO 66
      ALPHA = 0.0
      WRITE(6,248)ALPHA
C
 66   LAMBD1 = -SQRT(CT/2.)
      IF (MU .LE. 0.1)GO TO 68
      DP = PP * 550/VF
      ALPHA = -DP/W
      WRITE(6,247)DP,ALPHA
 67   LAMBDA = -CT/SQRT( 2*(LAMBD1**2) + MU**2) + MU * TAN(ALPHA)
      DLAMB = LAMBDA - LAMBD1
```

```
      LAMBD1 = LAMBDA
      LREF = ABS(ELAMB)
      IF (LREF .GE. LERR)GO TO 67
 68   LAMBDA = LAMBD1
C
C*********************************************************************
C* SOLVING SIMULTANEOUS EQUATIONS FOR CYCLIC AND COLLECTIVE ANGLES   *
C*********************************************************************
C
 31   E1 = (2.*CT)/(SC*CLA)
      E2 = T1*LAMEDA
      E3 = T3*TWIST
      D1 = ((2.*CT)/(SD*CLA)) - T1*LAMBDA- TWIST*T3
      D2 = -(A11*LAMBDA) - (TWIST*A13)
      CYCLIC = ((E2*T2)-(D1*A12)) / (T2*A14 - T4*A12)
      COLL = (D1 - T4*CYCLIC) / T2
      THETA0 = COLL * 57.29578
      THETA2 = CYCLIC * 57.29578
      WRITE(6,209)A11,A12,A13,A14,T1,T2,T3,T4,LAMBDA
C
C*********************************************************************
C* CALCULATION OF STALL DYNAMIC PARAMETERS & STALL CORRECTION FACTOR *
C*********************************************************************
C
      GAM = AMAX - COLL + CYCLIC
      CS = MU * GAM + LAMBDA
      BS = -MU * TWIST - GAM
      RT = (BS**2 - 4.*TWIST*CS)
      WRITE(6,229)RT
      IF(RT)20,19,19
 19   XS = (-BS + SQRT(RT))/(2.*TWIST)
      XO = -XS - BS/TWIST
      WRITE(6,215)GAM,CS,BS,XS,XO
      IF (XS - 1.)17,20,20
 17   IF(XS)20,20,21
C
C*********************************************************************
C*    CALCULATION OF STALL POWER                                     *
C*********************************************************************
C
 21   CPS = (SD / (24.*PI))*((1.-MU)**2)*(1.-XS)*SQRT(1.-XS**2)
      IF((XS+XO)/2. .GE. 1.0)KS = 1.0
      IF ((XS+XO)/2. .GT. 1.0)GO TO 24
C
C
C*********************************************************************
C*    CALCULATES INBOARD STALL CORRECTION IF (-BS/2TWIST < 1.0)      *
C*********************************************************************
```

```
C
      KS = -(BS/(2.*TWIST)+XS)/(1.-XS)
   24 CPS = KS * CPS
      GO TO 25
   20 CPS = 0.0
      KS = 0.0
   25 PS = CPS*RHC*AD*(VT**3)/550.
      WRITE(6,216)KS,CPS
C
C*********************************************************************
C*    ANGLE OF ATTACK CALCULATIONS                                   *
C*********************************************************************
C
      A90 = COLL + CYCLIC +TWIST + LAMBDA/(1.+MU)
      A270 = COLL - CYCLIC +TWIST + LAMBDA/(1.+MU)
      A90D = A90 * 57.29278
      A270D = A270 * 57.29278
C     WRITE(6,217)A90,A270
      WRITE(6,223)CYCLIC,COLL,A90D,A270D
C
C*********************************************************************
C*    CALCULATION OF COMPRESSIBILITY POWER                           *
C*********************************************************************
C
   26 MT = (VF+VT)/SVEL
      MCRIT = MCRC - CLA * A90 * .113
      IF (MT - 1.)28,27,27
   27 WRITE(6,240)
      GO TO 32
   28 DMD = MT-MCRIT- 0.06
      IF (DMD)32,32,30
   30 CPC = SC*(0.012*DMD+.1*(DMD**3))
      GO TO 33
   32 CPC = 0.0
      DMD = 0.0
   33 PM = CPC*RHC*AD*(VT**3)/550.
C
C     CALCULATION OF TOTAL POWER
C
      PT1 = PT+PM+PS
      WRITE(6,230)MT,MCRIT,DMD,CPC,PIT,PO,PP,PM,PS,PT1
      TSHP = 1.13*PT1 + 10.0
      VFK = VF / 1.68894
      VFK = VFK + DVFK
      IF (VFK .LT. VMAXK) GO TO 65
      CENT = CENT + 1
      IF (CENT .GT. 1)GO TO 97
      VFK = VMAXK
```

```
      IF (VFK .EQ. VMAXK) GC TO 65
 97   CONTINUE
C
C
C***********************************************************************
C*                                                                     *
C*    DETERMINATICN OF STALL ONSET VELOCITY                            *
C*                                                                     *
C***********************************************************************
C
      VOPT = SQRT(W/RHO/AD*SQRT(AD/3./FPA))
      VOPTK = VOPT/1.68894
      VSK = VCPTK
      WRITE(6,301)VSK
      VF = VFK * 1.68894
 37   MU = VF/VT
      PP = (.5 * RHO * FPA * (VF**3))/550.
      C1 = (BTL**2 + .5 * MU**2)
      C2 = (BTL**2 - .5 * MU**2)
      T1 = .5 * C1
      T2 = (BTL**3)/3. + (MU**2 * BTL * .5)
      T3 = (BTL**2/4.) * (BTL**2 + MU**2)
      T4 = (MU/2.) * (BTL **2 + MU**2/4.)
      A11 = ((BTL**2*MU*.5 - (MU**3/8.))*4.)/(BTL**2*C2)
      A12 = (8.*MU*BTL)/(3.*C2)
      A13 = (2.*MU*BTL**2)/C2
      A14 = (BTL**2 + 1.5*MU**2)/C2
C
C     CALCULATION OF INFLOW ANGLE LAMBDA
C
      ALPHA = -(PP*550.)/VF/W
      LAMBD1 = -SQRT(CT/2.)
      IF (MU .LE. 0.1)GO TO 71
 72   LAMBDA = -C1/SQRT(2*(LAMBD1**2) + MU**2) + MU * TAN(ALPHA)
      DLAMB = LAMEDA - LAMBD1
      LREF = ABS(DLAMB)
      IF (LREF .GE. LERR)GO TO 72
 71   CONTINUE
      IF (MU .LE. 0.1) LAMBDA = LAMBD1
C
C
C     SOLVING SIMULTANEOUS EQUATIONS FOR CYCLIC AND COLLECTIVE ANGLES
C
 74   E1 = (2.*CT)/(SD*CLA)
      E2 = T1*LAMEDA
      E3 = T3*TWIST
      D1 = ((2.*C))/(SD*CLA)) - T1*LAMBDA- TWIST*T3
      D2 = -(A11*LAMBDA) - (TWIST*A13)
```

```
      CYCLIC = (((C2*T2)-(C1*A12)) /  (T2*A14 - T4*A12)
      COLL = (D1 - T4*CYCLIC) / T2
      THETA0 = COLL * 57.29578
      THETA2 = CYCLIC * 57.29578
      A270 = COLL - CYCLIC +TWIST + LAMBDA/(1.+MU)
C
C     COMPARISCN CF ACTUAL A270 TO STATIC STALL ANGLE
C
      DA270 = A270 - AMAX
      DREF = ABS(DA270)
      IF (A270 .LE. AMAX)GO TO 85
      IF (A270 .GT. AMAX)GO TO 95
   85 IF (DREF .LE. DERR)GO TO 105
      VF = VF +  1.0
      GO TO 37
   95 IF (DREF .LE. DERR)GO TO 105
      VF = VF -  1.0
      GO TO 37
  105 VSK = VF / 1.68894
      WRITE(6,243)DREF,DERR
      A270D = A270 * 57.29278
      WRITE(6,241)A270D,VSK,VOPTK,VMAXK
C
      STOP
C
  200 FORMAT(5G12.6/,5G12.6/5G12.6)
  201 FORMAT(21X,'INPUT DATA'//)
  202 FORMAT('1',////15X,'HIGH SPEED FORWARD FLIGHT ANALYSIS'//)
  209 FORMAT(//10X,'DYNAMIC PARAMETERS',//,
     >       '      A11..............................',F10.6/,
     >       '      A12..............................',F10.6/,
     >       '      A13..............................',F10.6/,
     >       '      A14..............................',F10.6/,
     >       '      T1...............................',F10.6/,
     >       '      T2...............................',F10.6/,
     >       '      T3...............................',F10.6/,
     >       '      T4...............................',F10.6/,
     >       '      INFLOW RATIO (LAMBDA)............',F10.6/)
  215 FORMAT(//10X,'VALUES FOR DETERMINING STALL COEFFICIENT'//,
     >       5X,'GAMMA  =  ',F14.8/,5X,'CS     =   ',F14.8/,
     >       5X,'BS     =  ',F14.8//,
     >       5X,'XS     =  ',F10.7/,5X,'X0      =  ',F10.7//)
  216 FORMAT(5X,'INBOARD STALL CORRECTION FACTOR......',G16.9/,
     >       5X,'STALL PCWER COEFFICIENT.............',G14.8//)
  223 FORMAT(//5X,'ANGLE OF ATTACK CALCULATIONS'//,
     >       5X,'LONGITUDINAL CYCLIC ANGLE.......',F10.6/,
     >       5X,'LONGITUDINAL COLLECTIVE ANGLE...',F10.6/,
     >       5X,'ALPHA(90) (DEG).................',F10.6/,
```

```
     >        5X,'ALPHA(270) (DEG)..................',F10.6//)
229   FORMAT(//10X,'STALL POWER CALCULATIONS'//,
     >        5X,'RT..................................',G12.6/)
230   FORMAT(///10X,'HIGH SPEED MACH EFFECTS'//,
     >        5X,'ADVANCING BLADE TIP MACH NUMBER...',G12.6/,
     >        5X,'CRITICAL MACH NUMBER..............',G12.6/,
     >        5X,'DRAG DIVERGENCE MACH NUMBER.......',G12.6/,
     >        5X,'COMPRESSIBILITY POWER COEFF.......',G12.6///,
     >'     ***************************************************'/,
     >/'                  POWER REQUIRED'/,
     >'     ***************************************************'//,
     > '        INDUCED POWER = ',6X,G12.6/,
     > '        PROFILE POWER = ',6X,G12.6/,
     > '        PARASITE POWER = ',5X,G12.6/,
     > '        COMPRESSIBILITY POWER = ',G12.6/,
     > '        STALL POWER = ',9X,G12.6//,
     > '        TOTAL POWER REQUIRED = ',G12.6/)
236   FORMAT(/'      ***************************************************'/,
     >     10X,'FORWARD VELOCITY IN KNOTS     =  ',G12.6/,
     >        '      ***************************************************'/)
240   FORMAT(///5X,'TIP MACH NUMBER GREATER THAN OR EQUAL TO 1.0'///)
241   FORMAT(//'      ***************************************************'//,
     >       5X,'ANGLE AT STALL ONSET= ',3X,G12.6//,
     >       5X,'STALL ONSET VELOCITY = ',3X,G12.6//,
     >       5X,'VELOCITY MAX ENDURANCE = ',2X,G12.6//,
     >       5X,'MAXIMUM FORWARD VELOCITY = ',G12.6//,
     >        '      ***************************************************'/)
243   FORMAT(/5X,'DIFFERENCE BETWEEN A270 AND AMAX = ',G12.6/,
     >       5X,'ACCEPATABLE ERROR = ',G12.6/)
247   FORMAT(/'PARASITE DRAG = ',G12.6/,'DISK PLANE ANGLE OF ATTACK = ',
     >     G12.6/)
248   FORMAT(/5X,'DISK PLANE ANGLE OF ATTACK = ',F10.6/)
301   FORMAT(/5X,'INITIAL STALL ONSET VELOCITY APPROXIMATION (KTS) = ',
     >   G12.6/)
310   FORMAT('         COEFFICIENT OF THRUST.............  ',G12.6/,
     >        '         INDUCED VELOCITY..................  ',G12.6/,
     >        '         DISC AREA.........................  ',G12.6/,
     >        '         SOLIDITY..........................  ',G12.6/,
     >        '         TIP-LOSS FACTOR...................  ',G12.6/,
     >        '         GROUND EFFECT RATIO...............  ',G12.6//)
312   FORMAT('         RADIUS............................  ',G12.6/,
     >        '         MAIN ROTOR CHORD..................  ',G12.6/,
     >        '         NUMBER OF MAIN ROTOR BLADES.......  ',G12.6/,
     >        '         AICRAFT GROSS WEIGHT..............  ',G12.6/,
     >        '         ROTOR TIP VELOCITY................  ',G12.6/,
     >        '         HORIZONTAL FLAT PLATE AREA........  ',G12.6/,
     >        '         NUMBER OF ENGINES IN HELICOPTER..  ',G12.6//,
     >        '         DENSITY ALTITUDE..................  ',G12.6/,
```

```
     >          '     MAIN ROTOR HEIGHT ABOVE GROUND...     ',G12.6/,
     >          '     AIR DENSITY (RHO)...............     ',F12.5/,
     >          '     SONIC VELOCITY..................     ',G12.6/,
     >          '     BLADE GEOMETRIC TWIST...........     ',G12.6//,
     >          '     TYPE AIRFOIL....................     ',G12.6/,
     >          '     MAXIMUM 2-D LIFT COEFFICIENT....     ',G12.6/,
     >          '     2-D STATIC STALL ANGLE (AMAX)...     ',G12.7/,
     >          '     LIFT CURVE SLOPE (/RAD).........     ',G12.6/,
     >          '     ZERO-LIFT DRAG COEEFICIENT......     ',F12.6/,
     >          '     CRITICAL MACH NO (FOR CL = 0)...     ',F12.5//
     >          '     INITIAL FORWARD VELOCITY (KT)...     ',G12.5/)
C
      END
```

F. SAMPLE OF IBM COMPUTER OUTPUT

This section contains an example run of the IBM computer program, utilizing AH1-J Cobra data, starting at a forward velocity of 120 knots and terminating at VMAX.

```
HIGH SPEED FORWARD FLIGHT ANALYSIS

INPUT DATA

RADIUS...........................    22.0000
MAIN ROTOR CHORD.................    2.25000
NUMBER OF MAIN ROTOR BLADES......    2.00000
AICRAFT GROSS WEIGHT.............    10612.0
ROTOR TIP VELOCITY...............    738.000
HORIZONTAL FLAT PLATE AREA.......    17.0000
NUMBER OF ENGINES IN HELICOPTER..    2.00000

DENSITY ALTITUDE.................    1000.00
MAIN ROTOR HEIGHT ABOVE GROUND...    1000.00
AIR DENSITY (RHO)..............      0.002309
SONIC VELOCITY...................    1113.04
BLADE GEOMETRIC TWIST............   -.174500

TYPE AIRFOIL.....................    7.00000
MAXIMUM 2-D LIFT COEFFICIENT.....    1.40000
2-D STATIC STALL ANGLE (AMAX)....   .2443280
LIFT CURVE SLOPE (/RAD)..........    5.73000
ZERO-LIFT DRAG COEFFICIENT.....      0.010750
CRITICAL MACH NO (FOR CL = 0)..      0.720000

INITIAL FORWARD VELOCITY (KT)....    120.000

COEFFICIENT OF THRUST............    .554153E-02
INDUCED VELOCITY.................    38.8469
DISC AREA........................    1522.62
SOLIDITY.........................    .650197E-01
TIP-LOSS FACTOR..................    .947362
GROUND EFFECT RATIO..............    1.00000


*********************************************************
      FORWARD VELOCITY IN KNOTS   =   120.000
*********************************************************

PARASITE DRAG =  806.258
DISK PLANE ANGLE OF ATTACK = -.759760E-01


      DYNAMIC PARAMETERS

A11..............................   0.625400
A12..............................   0.806926
A13..............................   0.573338
A14..............................   1.175435
T1...............................   0.467602
T2...............................   0.319142
T3...............................   0.218296
T4...............................   0.125826
INFLOW RATIO (LAMBDA)............  -0.040381
```

STALL POWER CALCULATIONS

RT................................-.106778E-01

INBOARD STALL CORRECTION FACTOR...... .0
STALL POWER COEFFICIENT............. .0

ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE........ -0.109613
LONGITUDINAL COLLECTIVE ANGLE... 0.314954
ALPHA(90) (DEG)................. -0.048086
ALPHA(270) (DEG)................ 12.511999

HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER... .845135
CRITICAL MACH NUMBER............. .720543
DRAG DIVERGENCE MACH NUMBER....... .645919E-01
COMPRESSIBILITY POWER COEFF........ .521491E-04

****

POWER REQUIRED

****

INDUCED POWER =	151.545
PROFILE POWER =	296.464
PARASITE POWER =	297.103
COMPRESSIBILITY POWER =	134.001
STALL POWER =	.0
TOTAL POWER REQUIRED =	879.112

****

FORWARD VELOCITY IN KNOTS = 130.000

****

PARASITE DRAG = 946.234
DISK PLANE ANGLE OF ATTACK = -.891604E-01

DYNAMIC PARAMETERS

A11................................	0.680172
A12................................	0.880877
A13................................	0.625882
A14................................	1.207472
T1.................................	0.470875
T2.................................	0.325344
T3.................................	0.221234
T4.................................	0.136798
INFLOW RATIO (LAMBDA)............	-0.044668

```
STALL POWER CALCULATIONS

RT..............................-.7984162-02

INBOARD STALL CORRECTION FACTOR......  .0
STALL POWER COEFFICIENT.............. .0


ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE........ -0.122350
LONGITUDINAL COLLECTIVE ANGLE...  0.326189
ALPHA(90) (DEG).................. -0.291443
ALPHA(270) (DEG)................. 13.728103


HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER... .860309
CRITICAL MACH NUMBER.............. .723294
DRAG DIVERGENCE MACH NUMBER....... .770157E-01
COMPRESSIBILITY POWER COEFF........ .630606E-04

*****************************************************
                 POWER REQUIRED
*****************************************************

 INDUCED POWER =            139.900
 PROFILE POWER =            308.957
 PARASITE POWER =           377.740
 COMPRESSIBILITY POWER =    162.039
 STALL POWER =               .0

 TOTAL POWER REQUIRED =     988.636

*************************************************
     FORWARD VELOCITY IN KNOTS   =   140.000
*************************************************

PARASITE DRAG =  1097.41
DISK PLANE ANGLE OF ATTACK = -.103412


DYNAMIC PARAMETERS

A11................................  0.735630
A12................................  0.956563
A13................................  0.679659
A14................................  1.242629
T1.................................  0.474411
T2.................................  0.332042
T3.................................  0.224407
T4.................................  0.147888
INFLOW RATIO (LAMBDA).............. -0.050098
```

STALL POWER CALCULATIONS

```
RT.................................-.389701E-02

INBOARD STALL CORRECTION FACTOR...... .0
STALL POWER COEFFICIENT............. .0
```

ANGLE OF ATTACK CALCULATIONS

```
LONGITUDINAL CYCLIC ANGLE....... -0.136576
LONGITUDINAL COLLECTIVE ANGLE...  0.339933
ALPHA(90) (DEG)................ -0.520492
ALPHA(270) (DEG)............... 15.129103
```

HIGH SPEED MACH EFFECTS

```
ADVANCING BLADE TIP MACH NUMBER... .875484
CRITICAL MACH NUMBER.............. .725882
DRAG DIVERGENCE MACH NUMBER....... .896012E-01
COMPRESSIBILITY POWER COEFF........ .745873E-04
```

```
**************************************************************
                      POWER REQUIRED
**************************************************************
 INDUCED POWER =            129.913
 PROFILE POWER =            322.449
 PARASITE POWER =           471.789
 COMPRESSIBILITY POWER =    191.657
 STALL POWER =              .0

 TOTAL POWER REQUIRED =     1115.81

 **********************************************************
      FORWARD VELOCITY IN KNOTS    =    150.000
 **********************************************************
```

```
PARASITE DRAG =  1259.78
DISK PLANE ANGLE OF ATTACK = -.118713
```

DYNAMIC PARAMETERS

```
A11.............................  0.791849
A12.............................  1.034170
A13.............................  0.734801
A14.............................  1.281051
T1..............................  0.478208
T2..............................  0.339237
T3..............................  0.227815
T4..............................  0.159103
INFLOW RATIO (LAMBDA)........... -0.056720
```

STALL POWER CALCULATIONS

```
RT................................ .230777E-02
```

VALUES FOR DETERMINING STALL COEFFICIENT

```
GAMMA  =      -C.26459390
CS     =      -C.14755023
BS     =       0.32449627

XS     =      0.7921403
XO     =      1.C674362

INBOARD STALL CORRECTION FACTOR......  .662218C94
STALL POWER COEFFICIENT............. .31202595E-04
```

ANGLE OF ATTACK CALCULATIONS

```
LONGITUDINAL CYCLIC ANGLE.......  -0.152545
LONGITUDINAL COLLECTIVE ANGLE...   0.356377
ALPHA(90)  (DEG)................  -0.738687
ALPHA(270) (DEG)................  16.740753
```

HIGH SPEED MACH EFFECTS

```
ADVANCING BLADE TIP MACH NUMBER... .890658
CRITICAL MACH NUMBER.............. .728348
DRAG DIVERGENCE MACH NUMBER....... .102309
COMPRESSIBILITY POWER COEFF....... .867883E-04
```

```
****************************************************
                  POWER REQUIRED
****************************************************
 INDUCED POWER =             121.281
 PROFILE POWER =             336.941
 PARASITE POWER =            580.279
 COMPRESIBILITY POWER =      223.009
 STALL POWER =                80.1774

 TOTAL POWER REQUIRED =     1341.69

*************************************************
    FORWARD VELOCITY IN KNOTS    =    160.000
*************************************************

PARASITE DRAG =  1433.35
DISK PLANE ANGLE OF ATTACK = -.135068
```

DYNAMIC PARAMETERS

```
A11.............................  0.848907
A12.............................  1.113897
A13.............................  0.791449
A14.............................  1.322899
T1..............................  0.482267
T2..............................  0.346927
T3..............................  0.231457
T4..............................  0.170453
INFLOW RATIO (LAMBDA)............ -0.064591
```

STALL POWER CALCULATIONS

```
RT............................... .115852E-01
```

VALUES FOR DETERMINING STALL COEFFICIENT

```
GAMMA  =     -0.30194968
CS     =     -0.17515445
BS     =      0.36584556

XS     =     0.7398598
X0     =     1.3566751

INBOARD STALL CORRECTION FACTOR.......  1.00000000
STALL POWER COEFFICIENT............... .60549210E-04
```

ANGLE OF ATTACK CALCULATIONS

```
LONGITUDINAL CYCLIC ANGLE........ -0.170535
LONGITUDINAL COLLECTIVE ANGLE....  0.375743
ALPHA(90) (DEG).................. -0.949361
ALPHA(270) (DEG)................. 18.591431
```

HIGH SPEED MACH EFFECTS

```
ADVANCING BLADE TIP MACH NUMBER... .905832
CRITICAL MACH NUMBER.............. .730729
DRAG DIVERGENCE MACH NUMBER....... .115103
COMPRESSIBILITY POWER COEFF....... .997223E-04
```

```
****************************************************************
                      POWER REQUIRED
****************************************************************
```

```
INDUCED POWER =          113.722
PROFILE POWER =          352.433
PARASITE POWER =         704.243
COMPRESIBILITY POWER =    256.243
STALL POWER =             155.386

TOTAL POWER REQUIRED =   1582.23
```

```
****************************************************
     FORWARD VELOCITY IN KNOTS   =   163.359
****************************************************

PARASITE DRAG =  1494.16
DISK PLANE ANGLE OF ATTACK = -.140799


     DYNAMIC PARAMETERS

A11............................  0.868277
A12............................  1.141191
A13............................  0.810842
A14............................  1.337756
T1.............................  0.483689
T2.............................  0.349622
T3.............................  0.232734
T4.............................  0.174297
INFLOW RATIO (LAMBDA)........... -0.067526


     STALL POWER CALCULATIONS

RT.............................. .155987E-01


     VALUES FOR DETERMINING STALL COEFFICIENT

GAMMA   =     -0.31570089
CS      =     -0.18555188
BS      =      0.38093823

XS      =    0.7336488
X0      =    1.4493771

INBOARD STALL CORRECTION FACTOR......  1.00000000
STALL POWER COEFFICIENT..............  .611C8760E-04


ANGLE OF ATTACK CALCULATIONS

LONGITUDINAL CYCLIC ANGLE........ -0.177082
LONGITUDINAL COLLECTIVE ANGLE...   0.382947
ALPHA(90) (DEG)................. -1.019017
ALPHA(270) (DEG)................ 19.272018


     HIGH SPEED MACH EFFECTS

ADVANCING BLADE TIP MACH NUMBER... .910929
CRITICAL MACH NUMBER............... .731516
DRAG DIVERGENCE MACH NUMBER....... .119412
COMPRESSIBILITY POWER COEFF....... .104241E-03
```

```
****************************************************************
                PCWER REQUIRED
****************************************************************
  INDUCED PCWER =           111.388
  PROFILE PCWER =           357.861
  PARASITE PCWER =          749.536
  COMPRESIBILITY POWER =    267.855
  STALL POWER =             157.023

  TOTAL POWER REQUIRED =   1643.66

 INITIAL STALL CNSET VELOCITY APPROXIMATION (KTS) =  76.

 DIFFERENCE BETWEEN A270 AND AMAX =  .299871E-03
 ACCEPATABLE ERROR =  .100000E-02


 ****************************************************
 ANGLE AT STALL ONSET=      13.9811

 STALL CNSET VELOCITY =      131.913

 VELOCITY MAX ENDURANCE =     76.0347

 MAXIMUM FORWARD VELOCITY =  103.359
 ****************************************************
```

G. COMPARISON OF PROGRAM OUTPUT VS TEST DATA

This section compares the output of the HP41-CV and IBM 3033 computer programs to actual flight test data gathered at the Naval Weapons System Center.

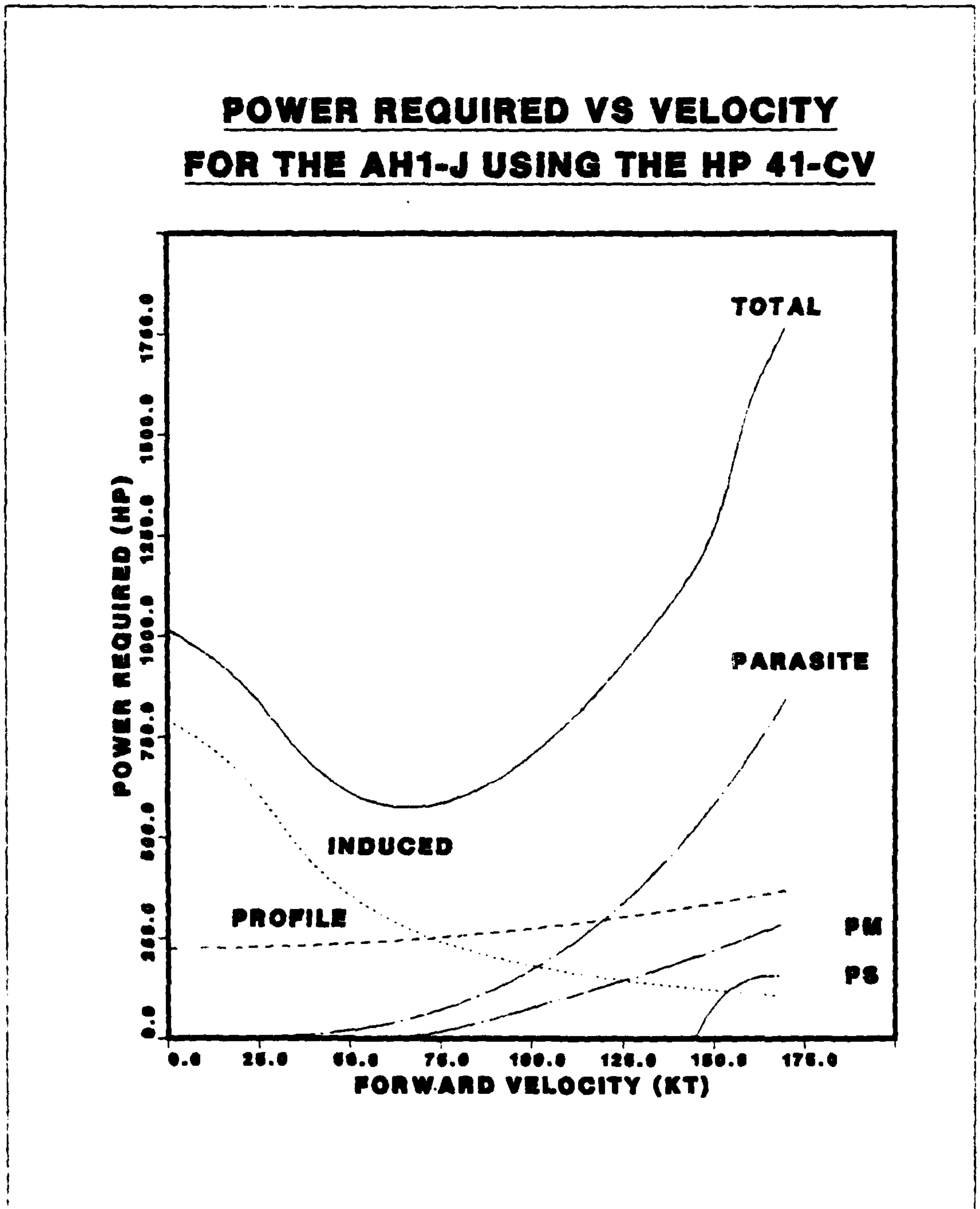


Figure C.1. Power Curves Generated by HP41-CV Program.

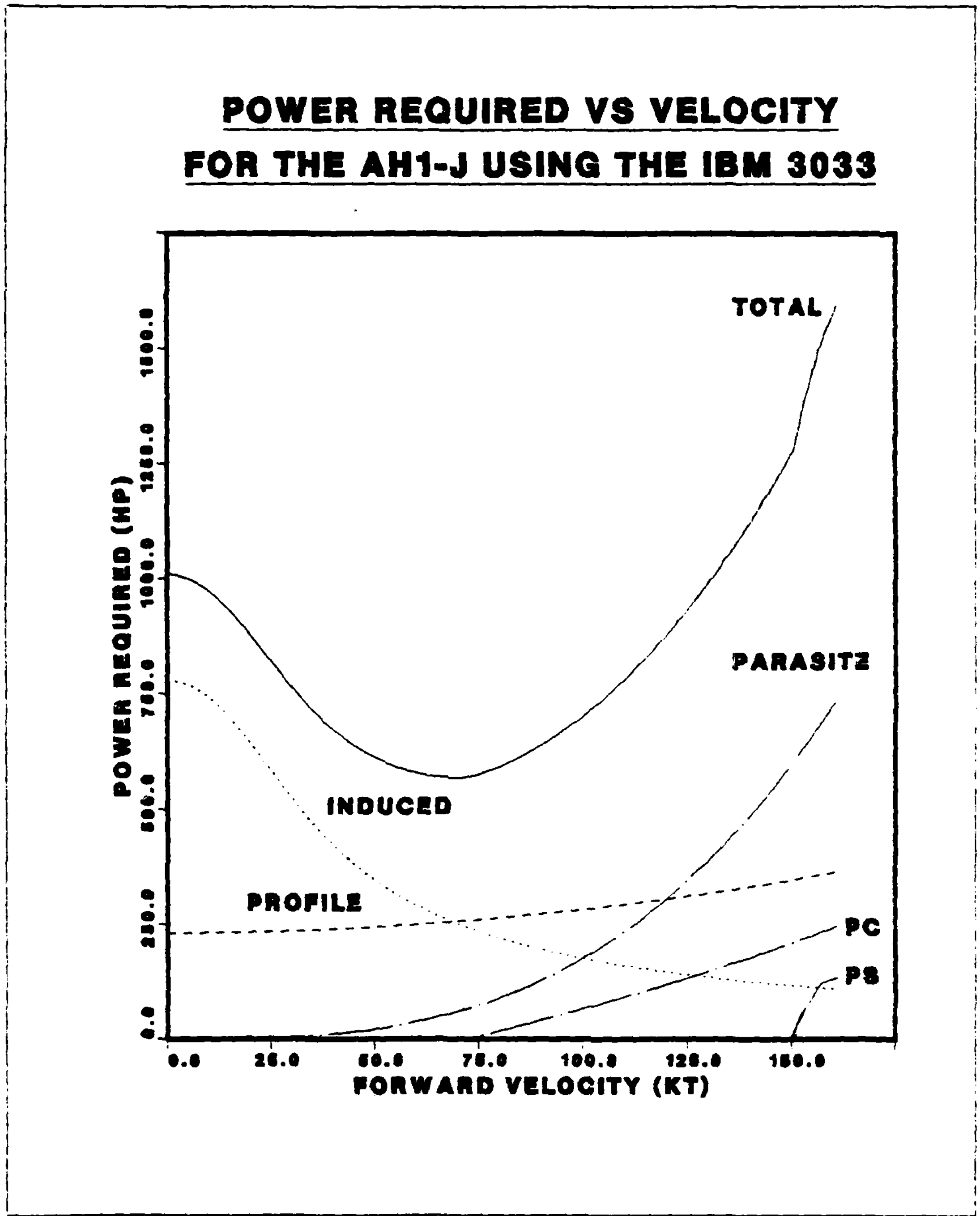


Figure C.2. Power Curves Generated by the IBM 3033 Program.

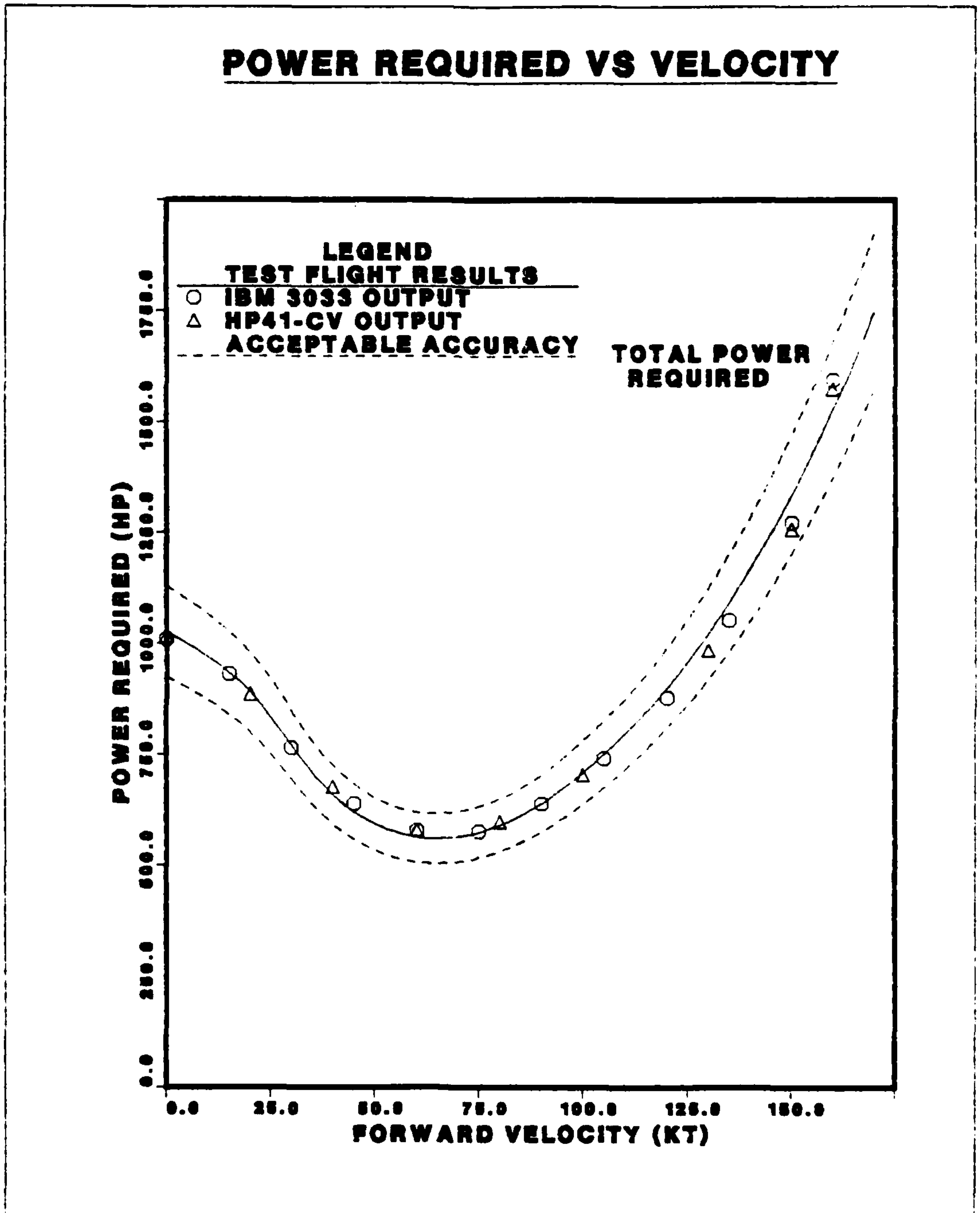


Figure C.3. Comparison Between Computer Data and Actual Test Flight Data.

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